Population Status of Inner Bay of Fundy Atlantic Salmon (*Salmo salar*), to 1999

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Table of Contents

Abstract v
Executive Summary 1
- Introduction 1
- Distribution 1
- Population 1
- Habitat 1
- Biology 1
- Limiting Factors 2
- Protection 2
- Summary of traits important to a Status Listing 2

Introduction 3
Distribution 4
- Identity of iBoF salmon 4
- Among rivers distributions 5
- Stocking history within iBoF 5
- Protection 6
- Population identity, trend and size 8
  - Population identity 8
  - Genetic information 13
  - Population trends – from commercial catch data 14
  - Population trend – from recreational catch data 15
  - Population size – from commercial catch data 16
  - Population size – from recreational catch data 17
- Established conservation levels 17
  - Big Salmon River – adult counts 18
  - Stewiacke River – adult counts 19
  - Point Wolfe River and Upper Salmon River (Alma) adult counts 20
  - Other iBoF rivers – adult salmon 22
  - Gaspereau River adult counts 22
  - Repeat spawning survival trends 23
- Juvenile salmon population trends 23
  - Stewiacke River 23
  - Big Salmon River 25
  - Other iBoF rivers 27
- Habitat 27
  - Freshwater 27
  - Marine 29

Biology 30
Limiting Factors 31
Special significance of the species 33
Recommendations 33
Evaluation 34
Acknowledgements 34
Literature Cited 35
Appendices i

Abstract

Wild anadromous Atlantic salmon (*Salmo salar* L.) of the inner Bay of Fundy (iBoF) have declined 90% or more in abundance since 1989. Although the stock has historically varied in abundance, the current decline is more severe and the population is at a lower abundance than previously documented. Recognition of the distinct phenotypic features of these stocks dates to the 19th century. Early maturity, prolonged successive annual spawning, local migration and distinct genetic profiles characterize at least two distinct stocks within the iBoF, one in the rivers of the Minas Basin and another in the rivers of the Chignecto Bay. The population was estimated to have been as many as 40,000 adult salmon in some years and likely less than 500 adult salmon in 1998. Annual recruitment to spawning of iBoF salmon stocks is not correlated with other Atlantic coast salmon populations. A reduction in repeat-spawning survival and survival to first spawning placed the stock in a steep decline. Monitoring of juvenile salmon in the two largest populations, Stewiacke and Big Salmon rivers, as well as in six other rivers of the iBoF, has confirmed that the decline is extensive within iBoF rivers. Since 1990 no fisheries have been permitted to harvest iBoF salmon. These data were assembled in September 1999 and submitted to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) for review in May 2001. Based on these data COSEWIC assigned a status of Endangered.

Résumé

L'abondance du saumon atlantique anadrome sauvage (*Salmo salar*) de l'arrière-baie de Fundy a décliné dans une proportion d'au moins 90 % depuis 1989. Quoique l'abondance des stocks ait varié par le passé, le déclin actuel est plus grave et l'effectif de la population est encore plus bas que ce qui avait été déterminé précédemment. La reconnaissance des caractéristiques phénotypiques distinctes de ces stocks remonte au XIXe siècle. Une maturité précoce, des frayes annuelles successives prolongées, des migrations locales et des profils génétiques distincts caractérisent au moins deux stocks séparés dans l'arrière-baie de Fundy, l'un dans le bassin des Mines et l'autre dans les rivières qui se jettent dans la baie Chignecto. On a estimé que la population avait compté jusqu'à 40 000 saumons adultes certaines années et sans doute moins de 500 saumons adultes en 1998. Le recrutement annuel à la fraye des stocks de saumon de l'arrière-baie de Fundy n'est pas corrélé avec celui des autres populations de saumon de la côte atlantique. Une diminution de la survie des géniteurs à frayes multiples ainsi que de la survie jusqu'à la première fraye ont occasionné un déclin abrupt du stock. La surveillance des saumons juvéniles au sein des deux plus grandes populations, soit celle des rivières Stewiacke et Big Salmon, ainsi que dans six autres rivières de l'arrière-baie de Fundy, a confirmé que le déclin est très prononcé dans les rivières de l'arrière-baie de Fundy. Depuis 1990, il est absolument interdit de pêcher du saumon de l'arrière-baie de Fundy. Les données présentées ici ont été réunies en septembre 1999 et soumises au Comité sur le statut des espèces menacées de disparition au Canada (CSEMDC), aux fins d'examen en mai 2001. C'est sur ces données que s'est fondé le CSEMDC pour attribuer le statut d'espèce menacée de disparition au saumon de l'arrière-baie de Fundy.

Executive Summary

Introduction

Wild anadromous Atlantic salmon (*Salmo salar* L.) of the inner Bay of Fundy (iBoF) have declined 90% or more in abundance to a level that places them at risk of extinction. Although the stock has historically varied in abundance, the decline since 1989 is more severe and the population is at a lower abundance than previously documented. Early maturity, successive annual spawning, local migration and distinct genetic profiles characterize two distinct stocks within the iBoF. Annual recruitment to spawning of iBoF salmon stocks is not correlated with other Atlantic coast salmon populations. Monitoring of juvenile salmon in the two largest rivers, Stewiacke River and Big Salmon River, as well as in six other rivers of the iBoF, has confirmed that the decline is extensive within iBoF rivers. River-specific population extinction has been noted.

Distribution

Rivers of the Minas Basin in Nova Scotia and of the Chignecto Bay in Nova Scotia and New Brunswick, as far south as the Black River, New Brunswick, supported at least two distinct stocks. Marine distribution is known to be local to the Bay of Fundy at least until late autumn and unknown for the winter season.

Population

Identity - Based on genetic markers, salmon of the iBoF are comprised of at least two distinct but related populations that represent distinct lineages of Atlantic salmon. Recognition of the distinct phenotypic features of these stocks dates to the 19th century. Collectively these stocks have been treated as a separate management unit since 1989.

Trend –Commercial and recreational catch data provide an indicator of the population trend that is variable. The populations have fallen markedly since the higher catches of the 1970s. Juvenile abundance data confirm the recent population declines.

Size – The population was estimated to have been as many as 40,000 adult salmon in some years, likely less than 500 adult salmon in 1998 and less than 250 in 1999.

Habitat

Freshwater - Atlantic salmon require clean, cool water free from chemical or organic pollution. While chronic loss of habitat may have occurred over the longer term there is no evidence of a substantial habitat loss since 1989. Brown trout (*Salmo trutta*), a species with similar habitat requirements, persist and have increased in many locations now vacant of juvenile salmon. These observations support the contention that productive capacity for juvenile salmon remains essentially unchanged since 1989.

Marine – The Bay of Fundy, a highly dynamic ecosystem, has provided essential habitat to support this population of Atlantic salmon. Disturbance to the ecology caused by tidal barriers and their effects on salmon are unknown. Extensive cage rearing of Atlantic salmon has developed in the marine habitat of iBoF salmon since the 1980s. There is some evidence of ecological change in the Bay of Fundy.

Biology

Inner Bay of Fundy salmon differ from most anadromous Atlantic salmon in their genetic lineage and marine distribution. Variable survival to first spawning places a dependence on the repeat-spawning component for population stability. A reduction in repeat-spawning survival and survival

to first spawning placed the stock in a steep decline. Uncertainty of the cause of recruitment failure and for population growth, makes predictions concerning the persistence or recovery of the stock unreliable.

Limiting Factors

Population growth of inner Bay of Fundy Atlantic salmon is and has historically been more often limited by marine survival than freshwater productive capacity.

Protection

In Canada, Atlantic salmon are directly protected under the Fisheries Act and because they require clean water they are indirectly protected under the Environment Act. Internationally, Canada is signatory to the North Atlantic Salmon Conservation Organization (NASCO). Since 1990 no fisheries have been permitted to harvest iBoF salmon.

Summary of traits important to a Status Listing

1. phenotypic and genetic distinctiveness,
2. small number of reproductive adults (less than 500 adults),
3. steep decline in population abundance in index rivers (≈90% in ten years),
4. under-distribution of juvenile salmon in freshwater habitat (79% of sampling locations in the Stewiacke River were void of age-0$^+$ parr in 1999, up from 0% in 1984),
5. persistent low survival from smolt to first spawning compared to historic measures,
6. decreased longevity (Big Salmon River aging data 1964 - 1972 compared to the Stewiacke aging data 1992 – 1995),
7. absence of any river population greater than the conservation requirement from which re-colonization of extirpated iBoF rivers might occur naturally.

Introduction

Atlantic salmon (*Salmo salar* L.) is a fish species that is endemic to the northern temperate hemisphere (MacCrimmon and Gots 1979). Domestic strains are now cultured in many temperate climates worldwide (Gross 1998). In the wild, salmon most often follow a life history that utilizes both marine and freshwater environments. Spawning and rearing occurs in fresh water and the major growth to maturity takes place in the ocean. When following this life history salmon are known as anadromous fish.

Atlantic salmon occur naturally in rivers around the North Atlantic Ocean. Anadromous Atlantic salmon in the southern portion of the range migrate during their usual one- to three-year marine phase to the northern extent of the Atlantic Ocean (Saunders *et al.* 1965). Northern North American stocks and some isolated European stocks have more localized migrations, e.g. Ungava Bay stocks in northern Canada (Power 1969) and Baltic Sea salmon stocks in Europe (Larsson 1984, Hansen 1993).

The continent of origin of Atlantic salmon can be identified with a high probability of success using mitochondrial and nuclear genetic markers. These markers reflect the genetic isolation and divergence (Verspoor 1986, Bermingham *et al.* 1991, Taggart *et al.* 1995) of Atlantic salmon. Within Europe, the distribution of allozyme and mitochondrial DNA (mtDNA) variation supports further significant regional isolation and divergence of Baltic and non-Baltic stocks (Stahl 1987, Verspoor 1997, Verspoor *et al.* 1999). Recent analysis of mitochondrial DNA shows regional differentiation within the southern part of the species' North American range (Verspoor *et al.* 2002, *in preparation at the time of the initial document*). Divergence among river populations appears hierarchically structured and generally increases with geographical scale (e.g. McConnell *et al.* 1997, Jordan *et al.* 1992). Some European and North American river stocks are fixed for different mtDNA variants (Taggart *et al.* 1995). Differences among river stocks within local regions are generally quantitative (e.g. Koljonene *et al.* 1999). However, using genetic markers only probabilistic identification and assignment of randomly sampled individuals to a population or river is possible (e.g. Koljonene *et al.* 1999, Galvin *et al.* 1995).

Metapopulation theory (Hedrick 1996, Hanski and Gilpin 1997), i.e. that isolated populations are potentially unstable components of a larger metapopulation, has been postulated by some to explain the complex stock structure of Atlantic salmon (Power 1981, Stephenson 1999). But, because of the degree of genetic and phenotypic heterogeneity among river populations, others (Fontaine *et al.* 1997, McConnell *et al.* 1997) have rejected metapopulation structure for Atlantic salmon. This debate is important to rare and endangered populations of salmon because of the practical implications for management or recovery planning (e.g. Young 1999). Under a metapopulation structure, periodic loss of some isolated populations are expected and of little or no consequence to the persistence of the metapopulation. However, maintenance of a large component of the metapopulation is necessary for stability.

Because of the uncertainty of the appropriate population model for Atlantic salmon, the selection of a cautious approach for the management of diverse populations has been ascribed. Therefore, wherever diverse structure among salmon populations has been observed, researchers recommend management based on the smallest definable population units, usually a river population (Fontaine *et al.* 1997, McConnell *et al.* 1997, King *et al.* 1999, Stephenson 1999).

Within the Bay of Fundy, on the East Coast of North America bordering Maine (USA), New Brunswick and Nova Scotia (Canada), at least two distinct population assemblages of Atlantic salmon have been suspected (Perley 1852, Huntsman 1931 a,b; Anon. 1986). One assemblage is referred to as outer Bay of Fundy, and includes rivers such as the Saint John River, New Brunswick. Within outer Bay of Fundy stocks, large salmon are most often females that mature

after two winters at sea and most males mature after one winter at sea. Tag recovery information and scale analysis indicate that outer Bay of Fundy salmon migrate to the North Atlantic Ocean. A second assemblage of salmon is found in rivers northeast of the Saint John River in New Brunswick and northeast of the Annapolis River in Nova Scotia. Salmon populations in these rivers are termed **inner Bay of Fundy** (iBoF) salmon (Perley 1852). Almost all salmon within these rivers have similar life history traits that differ from those of the outer Bay of Fundy. Inner Bay of Fundy salmon demonstrate more localized migration, earlier age at maturity and high survival between annual spawning events. Also, iBoF salmon appear to be more frequently dependent on repeat spawning for population stability (Amiro 1987).

The abundance of iBoF Atlantic salmon, as indicated by annual commercial salmon catches within the inner Bay of Fundy, has fluctuated widely and commercial catches have declined since the turn of the 20th century (Huntsman 1931a,b; Amirault *et al.* 1989). Since 1989, the population has declined to a critical low abundance. Annual stock status reports have been assembled since 1987 to advise fisheries managers of the status of iBoF salmon. Based on these reports all fishing for Atlantic salmon in any iBoF river has been prohibited since 1990. Salmon stock assessments in index rivers (from two to eight annually) have continued to document the decline to levels warranting immediate actions to prevent their extinction.

This document is, with editorial exceptions, a record of the status document submitted to the Committee on the Status of Endangered Wildlife in Canada and in part, upon which the Committee listed iBoF Atlantic salmon as "Endangered" in May, 2001. The document generally follows an outline prescribed by the Committee at the time of submission.

Distribution

Identity of iBoF salmon

Atlantic salmon from rivers of the inner Bay of Fundy are characterized by high frequencies of traits that are sometimes rare among other salmon populations and only observed collectively among iBoF salmon populations. Descriptive information obtained from salmon sampled in the Stewiacke River and Big Salmon River showed similarities in characteristics such as smolt age, age-at-maturity, frequency of repeat spawning, size-at-age, run time of smolts and run time of returning adults (Jessop 1975, 1986; Amiro and McNeill 1986). Annual recruitment to the sport fishery was significantly correlated among almost all of the salmon populations of the iBoF but was not correlated with Atlantic coast rivers (Amiro 1990e). The notable exception was Gaspereau River, Kings County, Nova Scotia.

Commercial catches of iBoF salmon were not correlated with Atlantic coast salmon stocks (Huntsman 1931a, Amiro 1990e) suggesting independence in productivity and recruitment. Twenty-two of these rivers could not be excluded as iBoF type salmon rivers based on stock characteristics, i.e. size of the fish, timing of the catch and annual recruitment pattern (Amiro 1987, 1990e).

More recently, mitochondrial DNA analysis has identified a genetic haplotype unique to the Minas Basin (including the Gaspereau River) and a rare haplotype shared by salmon from Minas Basin rivers and Chignecto Bay rivers (Verspoor *et al.* 2002, *in preparation at the time of the initial document*). Alone, these data suggest that the Minas Basin and Chignecto Bay salmon stocks, also known as iBoF salmon, may be considered as two "evolutionary significant units" or ESU's, as defined by Waples (1991, 1995).

Among rivers distributions

Based on recreational catch reports, at least thirty-two rivers of the iBoF are known to have supported anadromous populations of Atlantic salmon (Figure 1, Appendix 1). Based on physical characteristics of iBoF salmon all rivers of the iBoF except Gaspereau River, Kings Co., Nova Scotia, the Black (Mosher) River and Irish River, New Brunswick, were thought to have supported an inner Bay of Fundy-type salmon stock. The two largest iBoF rivers that do not have artificial barriers to migration of salmon are the Big Salmon River, New Brunswick and Stewiacke River, Nova Scotia.

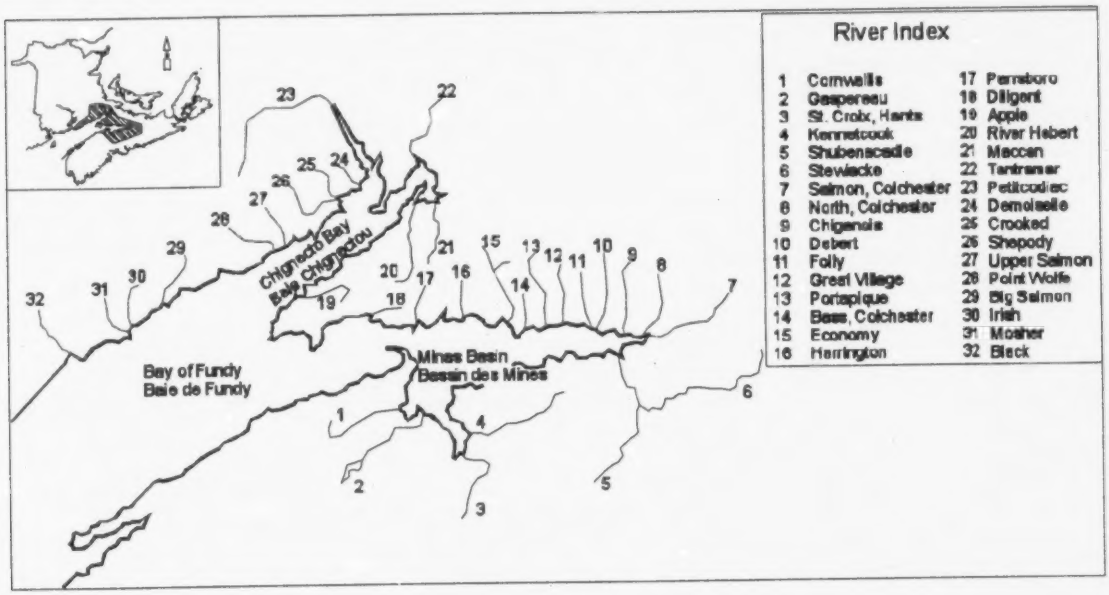

Figure 1. Map of the known Atlantic salmon rivers of the inner Bay of Fundy.

Stocking history within iBoF

A comprehensive list of the incidence of introductions of Atlantic salmon to the iBoF prior to 1976 had not been assembled and published at the time of this document. However, based on the literature cited below, at least six iBoF rivers were known to have been stocked with Atlantic salmon originating from outside the inner Bay of Fundy. These were Apple River, Maccan River, Big Salmon River, Petitcodiac River, Parrsboro River and Shubenacadie River.

The East Branch of the Apple River was stocked in 1932 and 1933 with salmon fry originating from broodstock taken from the Restigouche River at New Mills (Huntsman 1942).

The Maccan River was stocked in 1931 with salmon fry originating from broodstock captured in the Matapedia River, a tributary of the of the Restigouche River, New Brunswick/Quebec (Huntsman 1942).

The Big Salmon River was stocked, 1963 to 1966, with smolts of Miramichi River, Northwest Branch origin (Jessop 1976). The Big Salmon River was also stocked with smolts of Restigouche River origin in 1968 and 1969 (Jessop 1976).

The Petitcodiac River has been stocked with River Philip and Miramichi River origin fry from 1942 to 1946 (Elson 1962), Big Salmon River origin stock 1985 and 1986, a hybrid stock (Big Salmon

River crossed with Chamcook River), 1980, 1982 to 1986, 1991 and with Saint John River stock 1980, 1982 to 1987 and 1998 to 1999.

The Parrsboro River was stocked with Gaspereau River origin parr and smolts in 1997 and 1998.

The introductions to the Shubenacadie River are difficult to determine because a hatchery was operated at Wellington Station, Fletchers Lake Run, Grand Lake, Halifax County, from 1936 to 1966 when the hatchery ceased production. Many foreign stocks of salmon were cultured at this hatchery but none, other than those possibilities listed above, were intentionally released into iBoF rivers. However, losses from this hatchery were likely to end up downstream of the hatchery in the Grand Lake and therefore possibly into the Shubenacadie River. It is also possible that some releases could have migrated upstream to Lake Charles, a headwater lake flowing both into Fletcher Run and into the Shubenacadie Canal and the Dartmouth lakes system exiting at Dartmouth Cove in Halifax Harbour. Return migration from this route was highly unlikely because of poor fish passage and water management unfavorable to anadromous fish passage in the disused canal system.

The efficacy and persistence of introduced stocks into the Big Salmon River has been inferred from the larger annual salmon runs counted in the 1980s. However, recreational catches, which can be indicative of salmon run strength, were higher than average in most rivers of the iBoF in the 1980s when success for these introductions was inferred. Also, recent analysis of mitochondrial DNA of salmon showed that 32% of fish sampled had a rare haplotype. A total of 57% of fish sampled from the Big Salmon River in 1997 and 1998 contained that haplotype (Verspoor *et al.* 2002, *in preparation at the time of the initial document).* This variant is uncommon in populations outside the Bay of Fundy and was found in only 7% of the fish sampled outside the iBoF.

Enhancement of the production of iBoF salmon has occurred in the Big Salmon River, Stewiacke River, and Point Wolfe River. Only Big Salmon River broodstock have been used in the Big Salmon River enhancement since the 1970s. In the case of the Stewiacke River only native broodstock were used and in the case of the Point Wolfe River, a re-colonization project, Big Salmon River origin broodstock were used (Semple and Mercer 1987).

Stocking after 1976 is documented in the Atlantic salmon hatchery distribution database maintained by the Diadromous Fish Division of the Department of Fisheries and Oceans at the Bedford Institute of Oceanography. A summary of incidences of stocking within rivers of the iBoF (Appendix 2) indicates infrequent stocking with salmon from outside the iBoF area, some local introductions and mostly enhancement with native (river-of-origin) stock. Rivers receiving most of the introduced stocks are rivers that were extirpated of their original fish stock usually because of ineffective fish passage (e.g. Point Wolfe River, Petitcodiac River, Parrsboro River).

Protection

In Canada, Atlantic salmon are directly protected under the Fisheries Act and, because they require clean water, they are indirectly protected under the Environment Act. Internationally, Canada is signatory to the North Atlantic Salmon Conservation Organization (NASCO).

Within Canada, regulations are amended annually and applied to Salmon Fishing Areas (23 areas in Atlantic Canada and 11 zones in Quebec) and to specific rivers and sections of rivers within those areas (Figure 2). As a season advances, regulations can be varied depending on the stock abundance. Salmon rivers within the inner Bay of Fundy are located in Salmon Fishing Areas 22 and 23.

Figure 2. Map of Salmon Fishing Areas (SFAs) and Quebec Management Zones (Qs) in Canada.

The numbers of salmon caught as by-catch in other fisheries in SFA 22 and 23 were reduced by successive regulations beginning in 1980. All salmon have had to be released, alive or dead, beginning in 1985. All fish weirs of the inner Bay of Fundy were reduced to low weirs in 1983, which were known to be less effective than high weirs for catching salmon. These regulation changes in the Bay of Fundy fisheries were enacted to reduce the by-catch of salmon.

Commercial salmon fishing seasons were reduced by the 1984 Salmon Management Plan from ten weeks to three weeks. All commercial salmon fishing within SFA 22 and 23 was closed in 1985.

Native peoples have recognized the scarcity of Atlantic salmon in rivers of the iBoF and have not conducted a salmon fishery in iBoF rivers since 1990. Consequently, fishing agreements with

First Nations do not include harvest of salmon from inner Bay of Fundy rivers. The Native Council of Nova Scotia, a group representing Native people not specific to a Native Band Council, report that no effort or catch has been applied to or derived from inner Bay of Fundy rivers since 1990. The Native Council of Nova Scotia advised members in 1993 that the inner Bay of Fundy salmon population was below the level recommended for harvest.

Recreational fisheries in iBoF rivers were generally restricted to a fall season fishery. Most rivers except the Big Salmon River, which had a June and July fishery as well, opened in August and closed in October. Anglers were licensed to fish by artificial fly only and were subject to daily and seasonal catch limits. Catch limits were reduced from four salmon per day with no season limit to fifteen per season in 1983. In 1984, catch was limited to ten per season and reduced to eight fish per season in 1992. Size limits (fish ≥63.0cm were to be released) also came into effect in 1983. Recreational fisheries in iBoF have been subject to in-season reviews since 1989. In-season reviews were based on estimates of early (before September) returns to the Big Salmon River. In-season assessments indicated returns were less than conservation requirements and no salmon fisheries in the iBoF have opened since 1990. Escapements (fish surviving to spawn) to inner Bay of Fundy rivers have been below those required to meet conservation targets since 1989 (Anon. 1998, 1999a). All recreational salmon fisheries have been closed in iBoF rivers of SFA 22 and SFA 23 since 1990. Other recreational fisheries, such as the American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*) fisheries have closed areas within iBoF rivers to reduce the by-catch handling mortality of migrating post-spawned salmon.

In general, salmon harvest regulations have become increasingly more restrictive. The Port-au-Basque, Newfoundland, drift-net salmon fishery, a fishery known to intercept distant migrating Atlantic salmon, was closed in 1967. All commercial salmon fisheries in Maritime Canada (New Brunswick, Nova Scotia and Prince Edward Island) were closed in 1985 and all directed commercial salmon fisheries on insular Newfoundland have been closed since 1992. Because of the low at-sea abundance of large multi-sea-winter salmon (mostly two-sea-winter salmon), the Labrador Native food salmon fishery was closed in 1998.

Internationally, the salmon fishery in the coastal waters of Greenland has been under quota since 1977, was closed to commercial harvest in 1997, and the local food fishery was assigned a quota of 20t in 1998. Closures in these interceptory fisheries were not expected to have a detectable effect on iBoF salmon. This expectation was based on smolt tagging experiments conducted on the Big Salmon River, from 1966 to 1974, and in the Stewiacke River 1970 to 1990 (See Population Identity).

Population identity, trend and size

Population identity

Inner Bay of Fundy salmon have been managed as a single biological assemblage based on similarities in life-history, recruitment variation and genetic characteristics. Recognition of the inner Bay of Fundy salmon as a distinct population evolved over a period of more than one hundred years. Perley (1852) and Venning (1885) wrote of the irregular abundance and probable demise of the Bay of Fundy salmon. Huntsman (1958) again noted the demise of the salmon in the Shubenacadie in 1951 and the apparent asynchrony in recruitment compared to Atlantic coast salmon stocks.

Generally salmon enter iBoF rivers in the autumn. However, the Big Salmon River has an earlier run timing that is somewhat dependent on summer water levels (Ritter 1989). Recreational catches, used as an index of recruitment, were highly correlated among iBoF rivers but were not correlated with Moser River, Halifax Co., Nova Scotia, an Atlantic Coast river that supports one-sea-winter salmon returns (Amiro 1987 and 1990e).

The most unusual characteristic of inner Bay of Fundy salmon is their post-smolt distribution. Post-smolt is the term given to a salmon that has departed the river for the first time but has not passed a winter at sea (Allan and Ritter 1975). Carlin-tagged post-smolts of Big Salmon River origin have been recovered in commercial fish weirs along the Nova Scotia coast of the Bay of Fundy in July. Smolts were also recaptured in the high weirs of Passamaquoddy Bay and Grand Manan Island (Figures 3 and 4) in August to September (Amiro and Jefferson 1996). This distribution of post-smolts is not typical of outer Bay of Fundy salmon stocks such as the Saint John River. Typically, outer Bay of Fundy post-smolts were recovered in the coastal fisheries of Newfoundland in July and August (Ritter 1989).

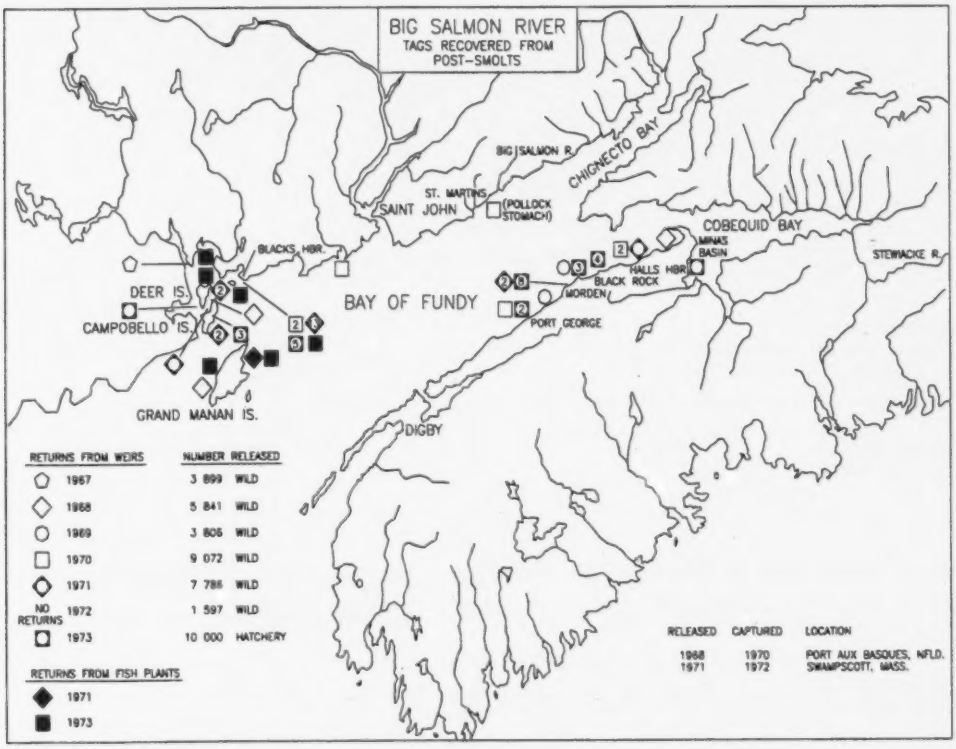

Figure 3. Post-smolt recapture locations of Big Salmon River tagged smolts, 1967 to 1973. Symbols indicate return years, number and locations of recaptures. Legend tables indicate numbers released and locations of two unusual recaptures (Amiro 1998b).

A total of 37,150 tagged Stewiacke River origin hatchery smolts have been released in the Stewiacke River since 1985. Stewiacke River tagged smolts were recaptured in the same fisheries and at similar times as those of the Big Salmon River. This data, considered with the similarities of life history, suggest that Stewiacke River post-smolts have a similar migration pattern as those of the Big Salmon River (Figure 4).

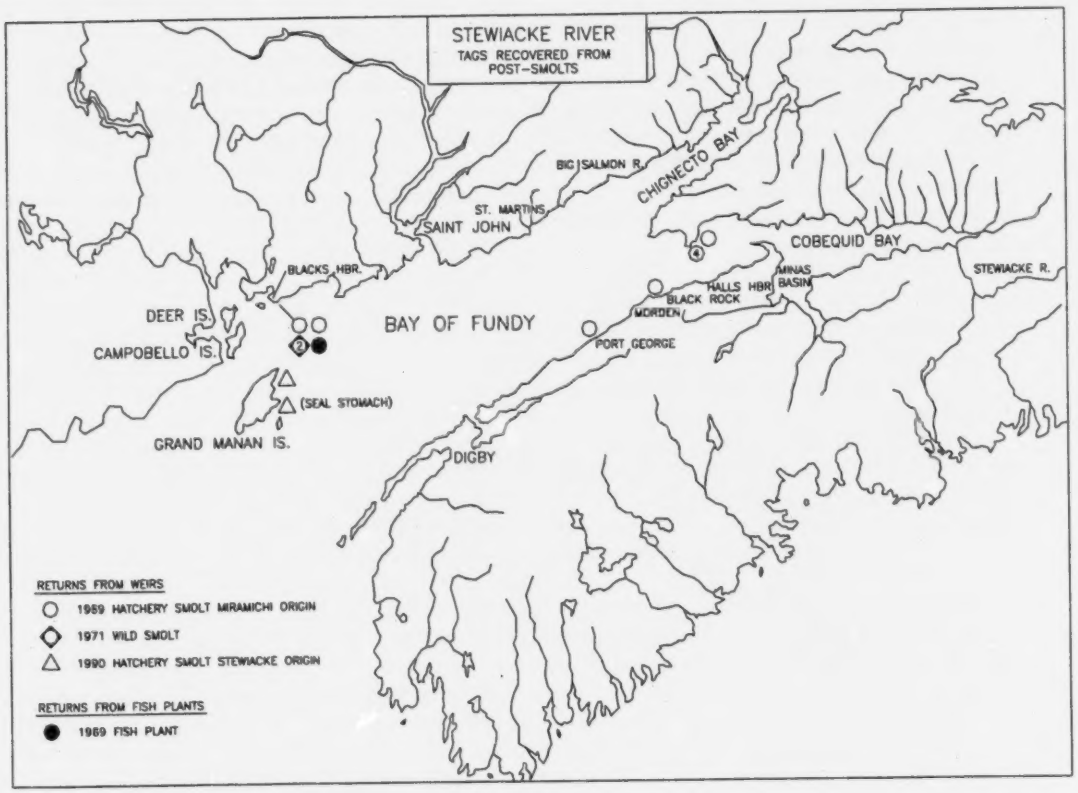

Figure 4. Post-smolt recapture locations from Stewiacke River tagged smolts 1970 to 1990. Symbols indicate year, location and numbers of recaptures (Amiro 1998b).

The distribution of inner Bay of Fundy post-smolts in the southern Bay of Fundy in the fall of the year, together with a lack of tag returns from interceptory fisheries, support the hypothesis that inner Bay of Fundy salmon do not utilize the North Atlantic for their winter habitat. While there is no direct information for the over-winter location of inner Bay of Fundy salmon, the tagging evidence indicates that inner bay of Fundy post-smolts spend significant time in the Passamaquoddy - Grand Manan Island areas during the late summer and autumn. Other stocks, e.g., Saint John River, are found in Newfoundland coastal waters at that time.

The difference in distribution of iBoF salmon from outer Bay of Fundy or Atlantic coast salmon is further supported by the recapture of mature adult salmon from these same iBoF releases. These releases resulted in only two iBoF tagged salmon being recovered from national or international interceptory fisheries (Figure 5).

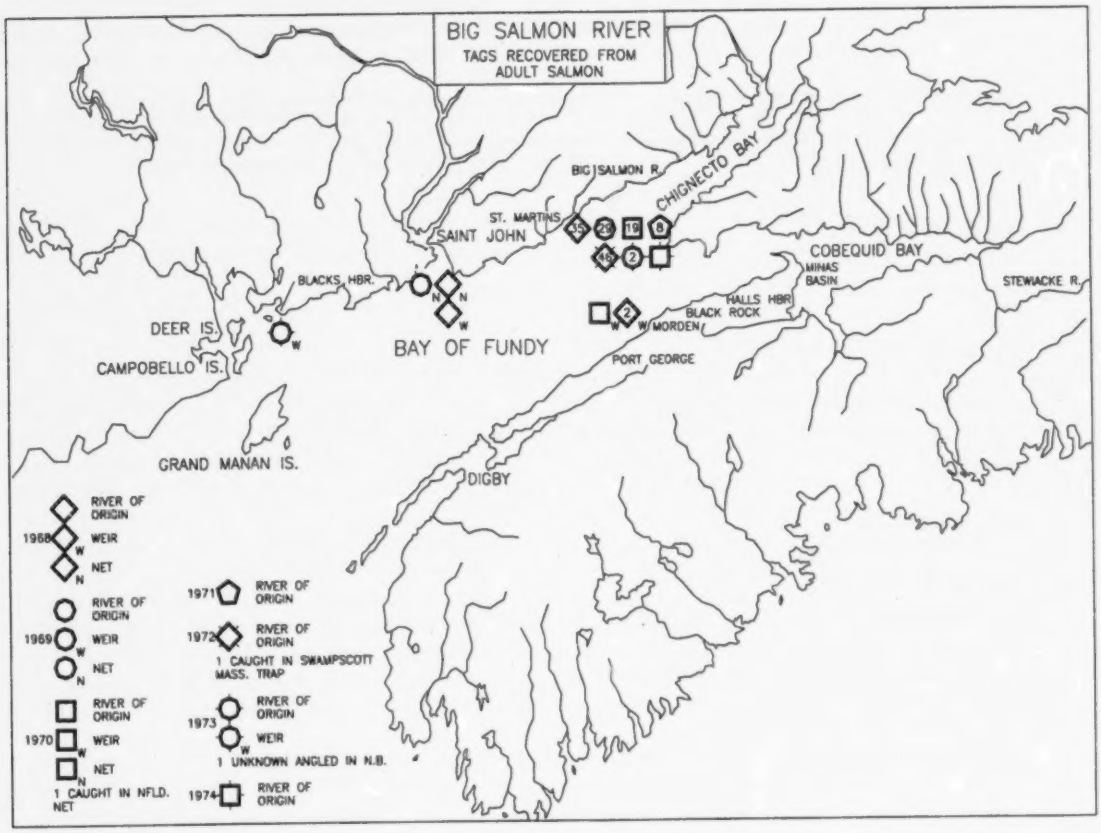

Figure 5. Adult salmon recapture locations of Big Salmon River tagged smolts, 1968 to 1974 (Amiro 1998b).

The most southerly tag recovery was from Swampscott Mass., USA. The most northerly tag recovery was from Port-aux-Basque, on the south coast of Newfoundland. All directed salmon fisheries have been closed in the USA since 1948 (Baum 1997).

When recaptures from 1985 to 1990 for iBoF tagged smolts were contrasted with concurrent releases of tagged smolts from outer Bay of Fundy and Atlantic coast rivers, the distribution of recaptures were not similar (Table 1). Because in-river recovery traps were not in place and little or no retention fisheries operated in iBoF rivers at that time, few adult salmon recoveries were expected in the iBoF rivers. However, if iBoF salmon utilized the North Atlantic as commonly as outer Bay of Fundy or Atlantic coast salmon, recoveries would have been expected to occur at similar rates.

Table 1. Numbers of tagged hatchery-grown Atlantic salmon released into twelve rivers in three areas of Atlantic Canada, numbers of recaptures of maturing salmon in two distant fisheries and numbers recaptured in their river-of-release, 1985 to 1990.

Area Stock	Number released	River recaptures	Newfoundland fishery	Greenland fishery	Other
Inner Bay of Fundy					
Big Salmon River	16,692 *a.*	0	0	0	0
Stewiacke River	15,652	0	0	0	0
Gaspereau River	9,446	2	1	1	0
Outer Bay of Fundy					
Saint John River	130,520	673	62	84	2
Saint John River	10,948 *a.*	3	2	0	0
Annapolis River	6,830	0	1	6	0
Atlantic Coast					
Tusket River	5,953	16	3	9	0
Medway River	16,875	10	11	1	1
LaHave River	76,702	622	58	101	0
Gold River	5,907	10	0	4	0
Musquodoboit River	21,648	14	6	34	0
Liscomb River	25,804	113	2	13	2
North River(Victoria Co.)	7,961	11	2	11	0

a. Released in the Petitcodiac River.

A contingency table based on the observed return rates from the Newfoundland and Greenland commercial fisheries among tag returns for iBoF and simultaneously obtained Atlantic coast river populations was developed to test the hypothesis of similarity in marine migration among stocks. Under this hypothesis, based on the Chi square distribution the probability of observing no recaptures in the interception fisheries for the Big Salmon River was 1.8×10^{-6}. The probability of zero recaptures for the Stewiacke River was 3.9×10^{-6}. The probability of simultaneously observing zero tag recoveries of iBoF origin tagged salmon in the Newfoundland and Greenland fisheries for both rivers and both fisheries is 7.2×10^{-12}. Thus, the null hypothesis of no difference among the marine distribution between iBoF and Atlantic coast stocks could be rejected.

River	Expected recaptures	River	Expected recaptures	River probabilities	Combined probability
Tusket	20.16	Big Salmon	22.75	1.848E-06	7.149E-12
Medway	7.11	Stewiacke	21.33	3.868E-06	
LaHave	20.73	Gaspereau	9.18	2.443E-03	
Gold	6.77				
Musquodoboit	18.48				
Liscomb	5.81				
North	16.33				

The Gaspereau River has an age distribution more similar to Atlantic Coast river stocks (Amiro and Jefferson 1996). The probability of obtaining the observed distribution of tag recoveries given

the Atlantic Coast tag recovery distribution record was p=0.002, indicating that the Gaspereau River may also have a migration somewhat different from Atlantic coast rivers and much different than other inner Bay of Fundy populations.

Collectively these data indicate that, unlike most Atlantic salmon stocks, few iBoF salmon utilize the North Atlantic for their winter marine habitat. Therefore, distant water fisheries were not expected to have contributed to the decline of most iBoF salmon.

Based on this information inner Bay of Fundy salmon were, for management purposes, considered in 1989 to be a distinct stock or population.

Genetic information

Allozyme studies in the late 1970s and 1980s provided early indicators of stock differentiation. Studies by Beland (1979) found a creatine phosphokinase (CK) variant at low frequency in both the Big Salmon (0.026) and Stewiacke rivers (0.060) which was absent in Penobscot, Magaguadavic and Miramichi (Rocky Brook) stocks. In a subsequent survey, Verspoor (1988) again detected the CK variant in the Stewiacke River. The variant was not detected in any of the several thousand salmon surveyed from populations elsewhere in Canada and Europe. The variant was found in only a single individual among 1,225 individuals screened from 13 non-iBoF Maritime rivers (E. Verspoor[1] unpublished data). Recent surveys of microsatellite locus variation in a number of Atlantic salmon stocks from across the species range have revealed an even more striking differentiation between salmon from the Stewiacke River and other rivers in eastern Canada (McConnell *et al.* 1995 a,b) as well as variation among iBoF rivers (McConnell *et al.* 1997). These studies revealed both major allele frequency differences in shared alleles as well as a few low frequency allelic variants unique to the iBoF stock.

Recent analysis of phylogenetically informative mitochondrial DNA (mtDNA) variation in stocks of Atlantic salmon from rivers in the southern sector of the species eastern North American range indicates the existence of two distinct evolutionarily defined populations (Verspoor *et al.* 2002, *in preparation at the time of the initial document*). Analysis of a 1,400 base pair (bp) section of the ND1/16sRNA region revealed the presence at moderate frequency of a restriction enzyme detectable DNA variant in all river stocks surveyed (including the Stewiacke R.) which is absent from stocks elsewhere in the species range in North America and Europe. Salmon from 18 rivers (9 from Inner Bay of Fundy rivers and 6 from other areas) were examined in more detail using an additional RFLP marker and sequence information. The mtDNA evidence (ND1-16SrRNA haplotypes and sequence data) suggested that salmon from the Inner Bay of Fundy rivers were genetically different from those from Southern Nova Scotia, Miramichi River and Newfoundland rivers as well as European stocks.

Within the Inner Bay of Fundy rivers two distinctive lineages were identified, each with a strong corresponding geographic component. One lineage was found in the rivers of the Minas Basin, and the other in the rivers of the adjacent Chignecto Bay, both in the upper reaches of the Bay of Fundy. Based on mitochondrial DNA analysis, it is clear that the Minas Basin portion of the inner Bay of Fundy salmon stock is a rare and distinct lineage. Salmon originating from rivers of the Minas Basin are genetically distinct from those in the outer Bay of Fundy as well as from stocks elsewhere in eastern Canada and Europe (Verspoor *et al.* 2002, *in preparation at the time of the initial document*). Analysis of the genetic information to date suggests that Chignecto Bay salmon may also comprise a unique lineage.

The first population encompasses fish from rivers draining into the Minas Basin of the inner Bay of Fundy. Economy, Portapique, Great Village, Folly, Stewiacke and Gaspereau rivers possessed

[1] E. Verspoor, Fisheries Research Services, Marine Laboratory, Aberdeen, Scotland.

a unique variant, which was missing from the Big Salmon, Irish, and Black rivers. This differentiation is highly significant (AMOVA -$p<0.0001$).

The boundaries of the second population, the Chignecto Bay lineage, were not as well resolved as those of the Minas Basin. More intensive analysis of base sequence variation in a 710 bp portion of the section revealed a further set of variants. One of these variants is shared between Minas Basin stocks and stocks in the northern section of the inner Bay of Fundy (rivers east of Cape Spencer including the Big Salmon River associated with the outer Chignecto Bay). The differentiation of these outer Chignecto Bay stock samples from samples from the outer Bay of Fundy Rivers (including the Saint John River) approaches significance (AMOVA - $p=0.112$).

Actual levels of differentiation detected are high but confirmation of the differentiation is hampered by small sample sizes. However, the potential consequences of a type II error (accepting a false null hypothesis that there is no difference between the populations) and rejecting the differentiation of the outer Chignecto stock group from outer Bay of Fundy stocks is unjustified. As a precaution, it is advisable to accept the existence of at least two evolutionarily defined Atlantic salmon populations in the inner Bay of Fundy - the Minas Basin and the Chignecto Bay stock groups.

Population trends – from commercial catch data

Commercial salmon catch reports as a surrogate of population trend could be misleading without evaluating extrinsic factors. Generally, the older the information the more uncertain the interpretation. This is because catches were sometimes landed in one area but reported in another. Effort was seldom known or reported. The number of licenses issued was not always an accurate measure of the number nets or traps fished. Also, two war periods in the time series, 1914 to 1918 and 1940 to 1945 may have changed the effort and consequently the exploitation rate independent of the population abundance. Furthermore, few management subdivisions can be certain to be fishing a single biological stock and reporting schemes changed as new management divisions were declared. For example, Westmorland Co., New Brunswick, has coastal waters on both the Bay of Fundy and the Gulf of St. Lawrence. Prior to 1940, data were reported for sub-sections of the district; after 1940, the districts were renumbered and while the coasts were separated, the division boundaries were slightly different.

All of these factors contribute to uncertainty in interpreting historic catch data. Dunfield (1986) provides a review and summary of the historic salmon catch information and, where detectable inaccuracies were uncovered, he adjusted the data. Dunfield's summations are the best available historic salmon catch summaries in Atlantic Canada.

According to Dunfield's summaries, commercial salmon catches for the years 1875 to 1940 from Albert and Westmorland Counties, New Brunswick, ranged down from 29,892 kg in 1915 to 22 kg in 1982 (Figure 6). Certainly, restrictions in the fishery such as season dates, gear types and license limits reduced the catch over this time period. However, because we are interested in population trend information, it is important to note that generally restrictions or reduction in effort occurred not because of the over-abundance of salmon, but, because of the scarcity of salmon. These data indicate the instability, production plateaus and decline of the iBoF salmon population since 1875.

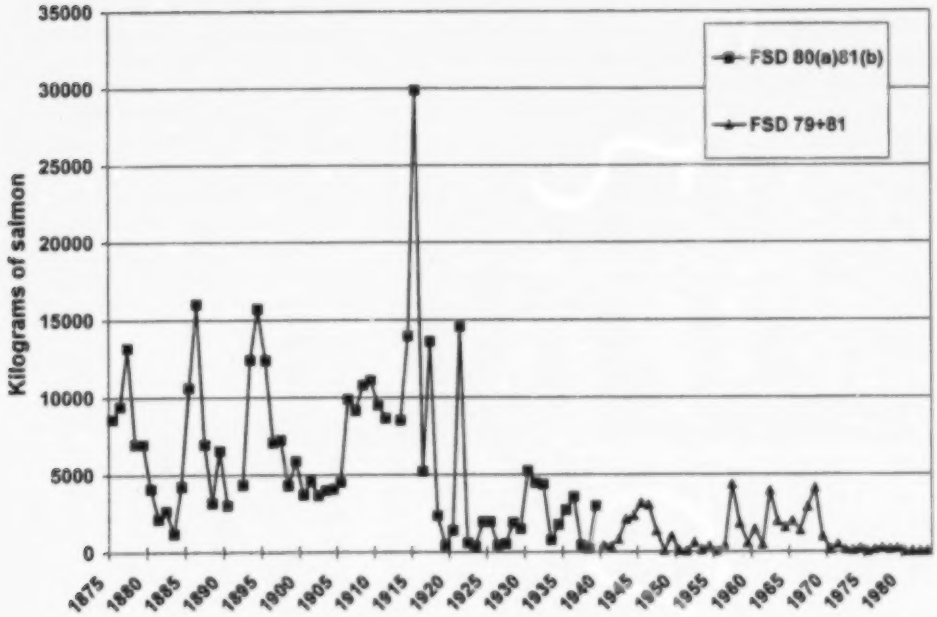

Figure 6. Commercial Atlantic salmon catches (kg) from Fisheries Statistical Districts 80(a) and 81(b), 1875 to 1940, and FSD 79 and 81, 1941 to 1984, (Albert and Westmorland Counties, New Brunswick). (R.W. Dunfield pers. comm.[2])

Population trend – from recreational catch data

Another source of information for trend in abundance of iBoF Atlantic salmon is the record of recreational salmon catches. As with commercial catch data, the accuracy and utility of recreational catch data can be uncertain. The source of the uncertainty is based on the possibility of reporting bias and the potential for high variability in exploitation rates. The impact of this uncertainty is dependent on the use one makes of the data. In this case, because few exploitation rates are known for iBoF salmon rivers, interpreting the population trend is more certain than using the data to estimate the population size. This is because the key assumption required for the trend analysis is that exploitation rate is a normally distributed variable with no temporal trend.

In the case of the iBoF rivers, the recreational fisheries regulations and seasons were altered to reduce exploitation in the years since 1984. Prior to 1984 the recreational fishery was unrestricted with regard to the number of anglers and restricted by gear type and daily possession limit (4 salmon). In 1984 mandatory release of salmon ≥63.0 cm was required in all recreational fisheries in SFA 22 and elsewhere. However, balancing the reduction in harvest caused by mandatory catch and release of salmon over 63.0 cm was over-reporting bias. Released catches were included in the catch records and are known to result in higher catch rates than exploitation rates. This is because of the possibility of multiple catch and release of a fish. Over-estimation bias can also be associated with catch and release reporting (Claytor and O'Neil 1991). To compensate for this bias, catch records are the sum of retained and released fish and were adjusted for time periods of over- or under-reporting (Marshall *et al.* 1988).

[2] R. W. Dunfield P.O. Box 2103, RR#2, Granville Ferry, NS B0K 1K0

Angling catches from inner Bay of Fundy rivers, 1970 to 1998 (Figure 8), averaged 1,462 large salmon (≥63.0 cm) and small salmon (<63.0 cm) and ranged from a high of 3,263 fish in 1983 to a low of 144 fish in 1980. The Stewiacke and Big Salmon rivers averaged 58% of the total inner Bay of Fundy recreational catch of salmon.

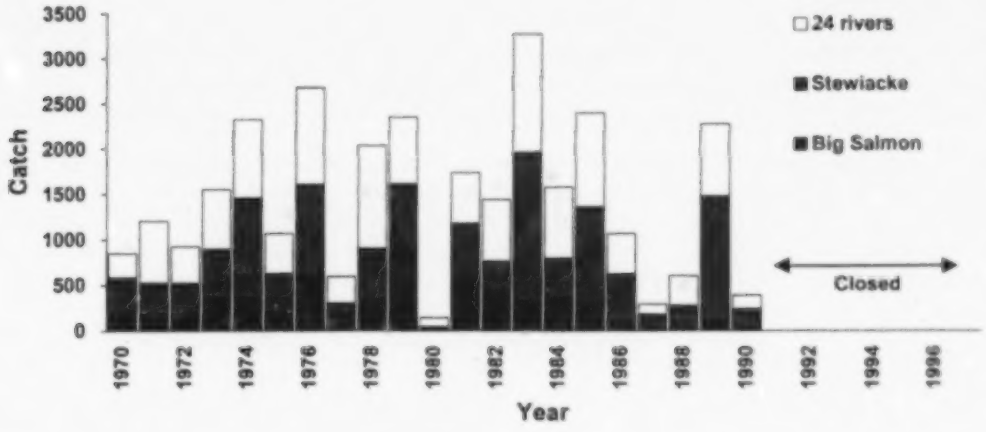

Figure 8. Recreational catches of small (< 63 cm) Atlantic salmon from the Stewiacke, Big Salmon and twenty-four other inner Bay of Fundy rivers, 1970 to 1998. Total catch indicated by stacked bars (Amiro and Jefferson 1996).

Angling catches in inner Bay of Fundy rivers declined after the recent high catch of 3,263 small salmon in 1983 (Figure 8). Low returns and catches in 1987 and 1988 alerted fisheries managers to possible conservation concerns for these rivers. The low recreational catch in 1987 and 1988 was not attributed to angling conditions. Higher returns, catches and escapements of salmon in 1989 seemed to briefly alleviate those concerns. However, neither the Big Salmon River visual counts nor the Stewiacke River fence count (1992-1994) indicate that these index rivers achieved conservation requirements since 1989.

Recreational catches were reported from 22 rivers from 1985 to 1989 (Appendix 1). Recreational catch data from this period are the most reliable in the series because of the standardization of catch reporting methods (see above). Only one river, Petitcodiac River, received hatchery supplementation with other than river-of-origin stock. Therefore, these data indicate that at least 22 of the 32 rivers of the iBoF maintained Atlantic salmon populations at that time.

Recreational catches in the Stewiacke River fell from 128 fish in 1958, to 7 fish in 1959, to none reported until 59 salmon were reported angled in 1962. While the reasons for the nil reports for 1959 to 1961 are unclear, low recruitment is suspected.

Population size – from commercial catch data

In the final years of the commercial fishery, the average weight of a salmon captured in Districts 79 and 81 was 3.0 kg in 1983 and 3.2 kg in 1984 (O'Neil *et al.* 1984). Using an average weight of 3.1 kg the historic catch data would suggest that, on average, there were 4,032 salmon captured in the iBoF commercial salmon fishery. Annual variation was high and the catch ranged from an estimated low of 6 salmon to a high of 9,611 salmon. There are no reliable estimates of effort that could be used to standardize the catch. There are no reported exploitation rates for iBoF salmon captured in these fisheries and therefore conversion of these catches to a total stock would require an assumed exploitation rate. Because there are no exploitation rates derived for these

fisheries and because these commercial fisheries (weirs and drift nets in estuaries) differ from other directed salmon fisheries, total population was not estimated from these data.

The commercial drift net fishery for salmon in Cobequid Bay and more often the tidal portion of the Shubenacadie River is thought to intercept salmon returning to the Shubenacadie River and to the Stewiacke River (technically the Stewiacke River is tributary to the Shubenacadie River below the head of tide). This fishery was monitored through a series of reports documenting annual catch obtained from sales slips and field officer reports prior to 1980 and individual fisher logbooks from 1980-1984 (Redbook Series[3]). Based on this information, the fishery took an average of 1,062 salmon per year weighing an average of 3.24 kg (Figure 7). Little information concerning a population trend can be gleaned from these data. The short duration of data record and closure of the fishery, as the result of the general reduction in commercial salmon fisheries, provides little useful information about the population trend.

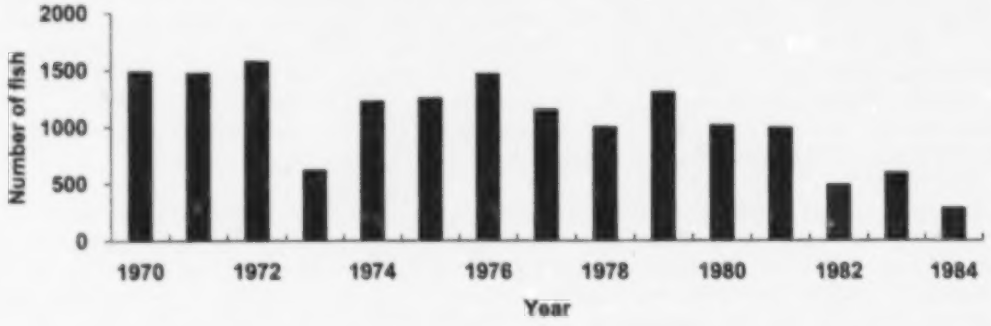

Figure 7. Recorded catch (numbers of salmon) from the Cobequid Basin (Districts 42 and 43) commercial salmon fishery 1970 – 1984 (Redbook Series DFO).

Population size – from recreational catch data

The average angling exploitation rate in the Big Salmon River 1964 to 1973 was 24.4% and ranged from 7 to 55% (Jessop 1986, Ritter 1989). Using an assumed 25% exploitation rate, similar to that observed in the Big Salmon River, suggests an average return of 5,849 salmon to rivers of the iBoF prior to 1989. Maximum returns could have been 46,614 salmon (3,263/0.25/0.07) and minimum returns could have been 262 salmon (144/0.55). The minimum estimate was derived from the 1980 return and a maximum exploitation of 55%. However, the low catch in 1980 was more probably due to a low exploitation rate rather than a low population. Precipitation and discharge were low in the summer and fall of 1980 (Amiro 1990e) and the angling season closed on October 15 before the salmon return was in the river. The likelihood of returns being as low as 262 salmon was not supported by electrofishing for juvenile salmon in 1981. Electrofishing density estimates conducted at two sites in the Stewiacke River in 1981 indicated a higher escapement in 1980 than a population estimate of 262 salmon for all iBoF rivers in 1980 would suggest. The densities at these two sites were 25.1 and 36.2 age-0+(fry) per $100m^2$. These densities are much higher than those observed in the late 1990s and are not indicative of an extremely low escapement to the Stewiacke River in 1980.

Established conservation levels

In the inner Bay of Fundy rivers, as in all Maritime rivers, conservation of Atlantic salmon is assessed by comparing estimates of the escapement of all salmon (or egg deposition) after

[3] Department of Fisheries and Oceans, Diadromous Fish Division, PO Box 1006, Dartmouth, N.S., B2Y 4A2.

fisheries to a required egg deposition or salmon escapement for all salmon producing habitat. Required depositions are set to produce juvenile and adult salmon at a level expected to maximize gain of the largest fish (Anon. 1986). This number of eggs or fish is known as the conservation requirement.

There is no scientific accepted minimum population established for Atlantic salmon. Therefore the conservation requirement for Atlantic salmon in the Maritimes Region of Canada is used as a threshold value for fisheries management purposes. The conservation requirement for management of Atlantic salmon is both the requirement and the limit reference point. This management system is a variation of that prescribed by the Food and Agriculture Organization of the United Nations (Anon. 1997) where two points, a limit and conservation reference point are generally used.

The conservation requirement, in addition to maximizing gain, satisfies the World Conservation Strategy to maintain the ecological process, genetic diversity and fullest sustainable advantage (Anon. 1991). In the absence of river- or stock-specific data to estimate river-specific production parameters, a value of 2.4 eggs m^{-2} of juvenile salmon rearing habitat (Anon. 1991) is used to derive the conservation requirement for most rivers in Eastern Canada. This value was determined to maximize production of smolts and gain of adult salmon in several Maritime salmon streams including the Pollett River, a tributary of the Petitcodiac River, an iBoF river.

All rivers of the iBoF except the Petitcodiac River and the Avon River (both affected by tidal causeways) were surveyed for Atlantic salmon habitat by a standard aerial ortho-photographic method (Amiro 1993). All accessible area of freshwater stream habitat suitable for rearing juvenile salmon was included. Biological characteristics of salmon used to estimate the requirements for each river were derived from samples taken from the Big Salmon River and the Stewiacke River. Biological characteristics included age-distribution, size-at-age, gender-at-age and length-fecundity. Based on estimates of accessible salmon production area and biological characteristics, the conservation requirement for 28 iBoF rivers was estimated at 10,220 salmon (O'Connell *et al.* 1997).

The status of adult Atlantic salmon has been assessed in only five iBoF rivers: Gaspereau River, Stewiacke River, Big Salmon River, Alma (Upper Salmon River) and Point Wolfe River. Methods for counting adult salmon varied and offer a range of accuracy, bias and perhaps error. Efforts have concentrated on the two most abundant iBoF salmon populations of the past twenty-nine years, the Stewiacke and Big Salmon rivers. Assessments for the Alma and Point Wolfe rivers are not model-based and therefore are considered anecdotal. Estimates for the Gaspereau River were obtained using a trap in the fishway and while accurate, for reasons previously described, do not represent recruitment of iBoF salmon in general.

Big Salmon River – adult counts

The Big Salmon River had a fishway in a dam at the mouth of the river that was removed in 1963. Counts were made in the fishway 1954 to 1962. The efficiency and completeness of the count in the fishway are uncertain. A fish counting fence installed in 1964 and operated through to 1972 was used to examine the escapement and biology of Big Salmon River salmon. Counts made at the fence, both upstream and downstream after adjustments for breaches are thought to be accurate measures of migrations during that period (Ritter 1989). It must be noted however that relative to other iBoF rivers, counts to the Big Salmon River during that period may have been affected by the return of hatchery-raised smolts.

Streamside observation and counts by divers have been conducted since 1990. In these cases, the population estimates are not model-based e.g. mark and recapture estimates, and therefore have unknown bias and error. However, water in the Big Salmon River is clear and visibility is frequently excellent. Where model-based estimates were conducted in rivers of this water quality

and size, the observation rates are high (e.g. Marshall *et al.* 1999: mean and standard deviation 0.634±0.10). The clear water and the level of expertise of the observers lend support for the accuracy of the estimates of salmon returns to Big Salmon River from 1989 to 1999. Collectively, these data show an increasing population during the 1960s and 1970s and a decline in the 1990s (Figure 9).

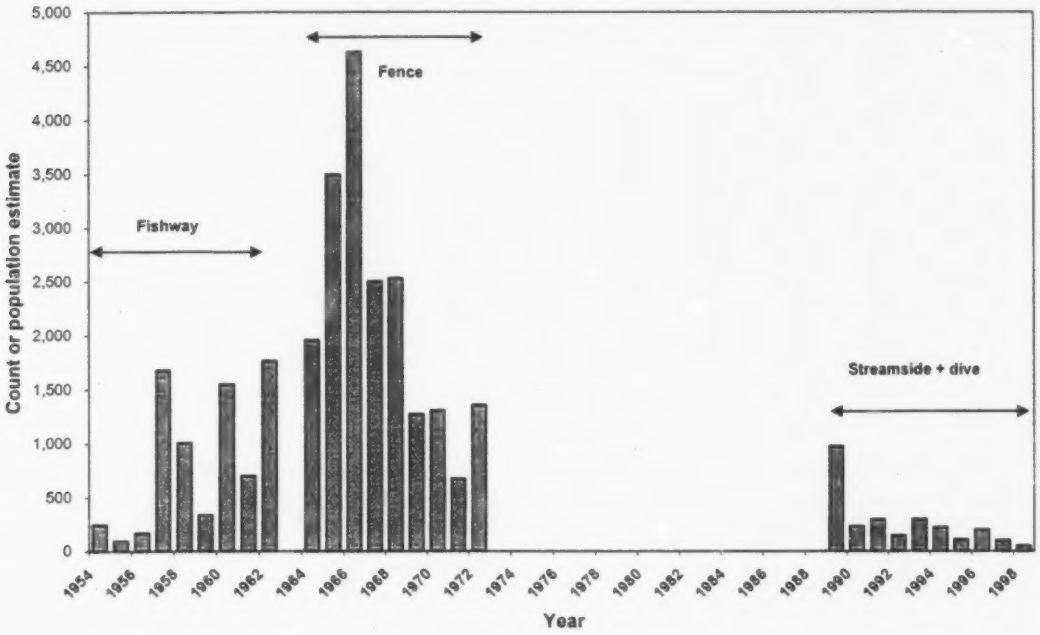

Figure 9. Counts of adult Atlantic salmon made in Big Salmon River, New Brunswick 1964 to 1998. Counts were taken at a fishway located in a dam that was breached in 1963, at a fish counting fence and by streamside observation and snorkel diving. Streamside observations were conducted before sea-cage-reared adult salmon were released in 1994 and 1995.

Stewiacke River – adult counts

Estimates of the adult returns to the Stewiacke River 1988 to 1998 were derived from counts at a fish counting fence at the head of tide, 1992 to 1995 and catch rates from electrofishing boat cruises 1988 to 1998. Fence counts were incomplete in 1992 and 1993 and therefore population estimates were derived by mark and recapture methods for those years. Electrofishing boat cruises of up to 41.09 km of the main river were standardized to salmon captured per km. Estimates derived from the fence were used to calibrate the boat catch-rate and thus derive some of the escapement estimates.

In 1998, no salmon were captured during the standard cruise (41.09 km of river). An estimate for 1998 was therefore derived from the significant ($p=0.0007$, R^2 adj $=0.64$.) relationship between mean fry density in 27 to 44 sites in the Stewiacke River and the ten annual population estimates available. The 1988 to 1998 time series of adult salmon escapement estimates indicates a declining population, which was less than 100 fish in 1997 and 1998 (Figure 10). The 1998 population is 12.5% of the 1989 population estimate.

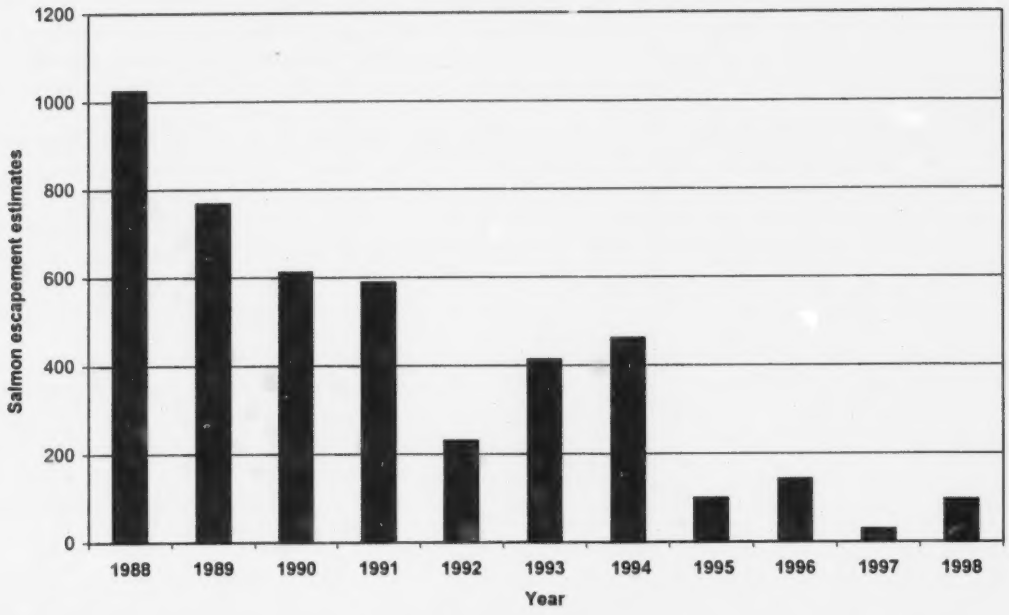

Figure 10. Atlantic salmon population estimates for the Stewiacke River derived from electro-boat catch per km calibrated to mark and recapture estimates using marks applied at the counting fence, 1992 and 1993, and to average fry densities 1989 to 1999 (see text for derivation).

Point Wolfe River and Upper Salmon River (Alma) adult counts

Personnel of and contractors to Parks Canada from 1963 to 1994 recorded the numbers of adult salmon observed in the fall of the year in the Upper Salmon and Point Wolfe rivers. Based on the small size of the rivers and the clarity of the water these may be considered as near complete population estimates. The counts show declines similar to the Big Salmon River and the Stewiacke River.

Table 2. Number of Atlantic salmon counted from the bank (streamside) and or under water (snorkeling) observation in the Point Wolfe River 1985 – 1990, 1992 and 1994 and the Upper Salmon River, 1963, 1965 – 1967, 1976 –1992, and 1994. Data provided by Fundy National Park and M. Jones (pers. comm.)[4].

	Point Wolfe			Upper Salmon		
Year	Grilse	Salmon	Total	Grilse	Salmon	Total
1963						100
1964						
1965						312
1966						600
1967						1200
1968						
1969						
1970						
1971						
1972						
1973						
1974						
1975						
1976						400
1977						300
1978						400
1979						900
1980						200
1981						500
1982						500
1983				372	168	540
1984				200	183	383
1985	196	4	200	276	95	371
1986	66	29	95	37	66	103
1987	36	39	75	23	29	52
1988	25	24	49	33	24	57
1989	161	17	178	250	41	291
1990	37	14	51	37	9	46
1991				28	12	40
1992			7			10
1993						
1994			8			15

[4] M. Jones, Department of Animal and Poultry Science, University of Guelph, Guelph, ON N1G 2W1

Other iBoF rivers – adult salmon

In 1998 and in 1999 few adult salmon could be located in any river of the iBoF. Estimates of escapements based on streamside observation and some snorkel diving, ranged from <50 for the Big Salmon River (T. Pettigrew, pers. comm.)[5] to zero for five rivers of the Nova Scotia portion of the iBoF (Debert, Folly, Portapique, Maccan and Apple). Adult salmon surveys conducted in seven rivers (those listed above and including the Salmon River, Truro and the Stewiacke River) during October and November of 1998 located only two mature Atlantic salmon. No salmon were reported in rivers of the Fundy National Park in 1998 (i.e. Pointe Wolfe and Alma rivers). In 1999 only one adult Atlantic salmon was captured during the autumn electrofishing boat cruise on the Stewiacke River.

Based on estimates of the adult salmon returns and escapements to the Stewiacke (96 salmon) and Big Salmon River (≈ 50 salmon) in 1998 and the fact that these rivers historically comprised 58% of the iBoF recreational catch, the 1998 population of iBoF salmon is estimated at about 250 salmon. Without the rigor of a model-based estimate, it is difficult to place a confidence on this number. However, based on the results of the 1999 electrofishing (see Figures 11, 13 and 14), it is highly probable that there were less than 500 sea-run adult salmon of iBoF origin that spawned in 1998.

Gaspereau River adult counts

Based on mitochondrial DNA analysis and gene sequencing, Gaspereau River salmon were derived from the same lineage as other Minas Basin salmon rivers (Verspoor *et al.* 2002, *in preparation at the time of the initial document)*. However, salmon of the Gaspereau River are also known to migrate to the north Atlantic and follow a recruitment and life history pattern similar to Atlantic coast rivers. This phenotypic difference can be seen in the percent of conservation requirement attained in 1997, when the Stewiacke River was at the 3% level, presumably like other Minas Basin salmon rivers, and the Gaspereau was at 74% (Table 3). While the population of salmon in the Gaspereau River may have been comprised of significant numbers of hatchery fish, enhancement of iBoF rivers with hatchery smolts in Minas Basin rivers was unsuccessful at that time due to low marine survival. Nonetheless, like many Atlantic coast salmon rivers the Gaspereau River population has declined since 1997 and is based on over 50% hatchery-produced smolts. The unique nature of the stock together with its recent decline provide sufficient reason to consider the viability of the population as uncertain and given its rarity, especially worth protective actions.

Table 3. Counts of small (<63 cm) and large (≥ 63cm) Atlantic salmon in the Gaspereau River fishway at White Rock, by wild and hatchery origin, number retained for broodstock and percent of the conservation requirement in the returns that was met, 1997 to 2000.

	Wild		Hatchery		Total return		Grand	% of
Year	Large	Small	Large	Small	Large	Small	Total	requirement
1997	12	53	7	30	19	83	102	74
1998	9	16	12	62	21	78	99	72
1999	13	15	13	0	26	15	41	30
2000	7	21	13	35	20	56	76	55

[5] Mr. T. Pettigrew, Regional Biologist, Department of Natural Resources, 80 Pleasant Street, Miramichi E1V 1X7

Repeat spawning survival trends

The Big Salmon River fence data can be used to derive annual survival values from the first to the sixth spawning of 40%, 72%, 39%, 24%, 16% and 14% (Appendices 4, 5 and 6). Data from the Stewiacke River fence, 1989 to 1993, indicated survivals from first to fourth spawning of 7%, 16% 0% and 0% (Amiro and Jefferson 1996). Compared to estimates derived from the Stewiacke River recreational and estuarial fishery obtained in 1983, the Stewiacke River fence data indicated that annual survival between spawning returns declined by 82% between first and second spawning and 92% between second and third spawning. These data suggest a shortened adult age distribution and a loss in the reproductive potential of the population.

Juvenile salmon population trends

Stewiacke River

No electrofishing was reported for the Stewiacke River 1958 to 1965 when recreational and commercial catches were low. Data collected in 1968 at six locations in the Stewiacke River indicated an average total parr (age-1^+ and age-2^+ not including age-0^+ i.e. fry) density of 14.5 per 100 m^2 (Carey 1968). This compares to an average parr density of 24.3 per 100 m^2 for the 1984 to 1993 period and 4.8 per 100 m^2 for the 1994 to 1999 period. These data indicate that the recent decline represented by the 1994 to 1999 electrofishing is more severe than that observed in 1968 after a previous population low.

A consequence of low recruitment of salmon has been a decline in parr populations in inner Bay of Fundy rivers. Density of salmon parr at 27 to 44 electrofishing sites in the Stewiacke River has declined since 1987 to levels typical of stocks impacted by low escapements or high in-stream mortality of eggs or parr (Figure 11). Juvenile sampling in the Stewiacke River is conducted under a weighted stratified random sampling protocol and therefore is more robust to sampling bias than simple random sampling. Stream gradient and distance from the mouth were used to classify the entire river. Sampling locations, sections between 5.0 m contour intervals, were randomly selected to represent the proportion of the total river area that a gradient-distance category represents of the total area (Amiro 1993). A variety of sampling equipment and techniques were tested and used to obtain as unbiased estimates of the population, distribution and abundance of juvenile salmon as possible (Amiro 1990 a,b,c).

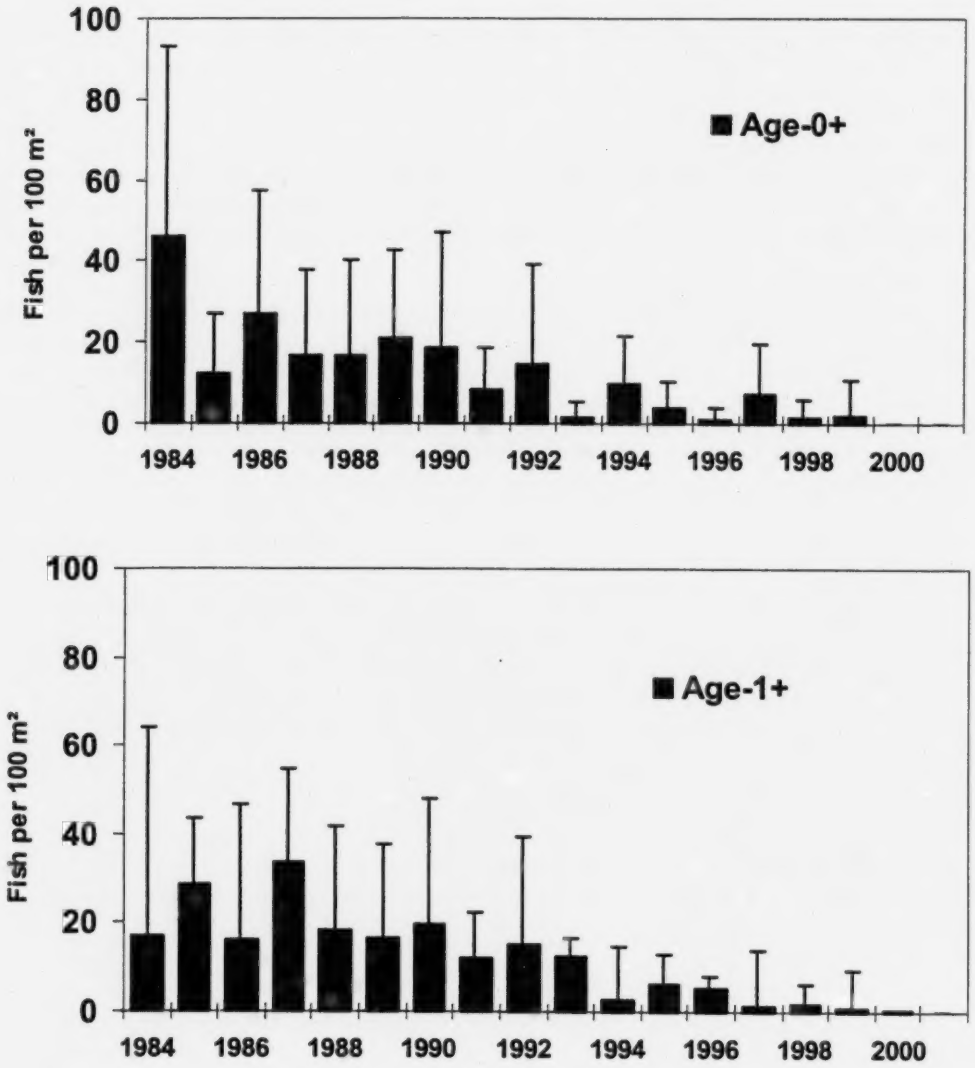

Figure 11. Stewiacke River age-0^+ and age-1^+ parr average density per 100 m^2 for 27 to 44 electrofishing sites 1984 to 1999.

The proportion of sites that contained age-0^+ parr decreased from 100% of 44 sites in 1984 to 21% of 33 sites in 1999 (Figure 12).

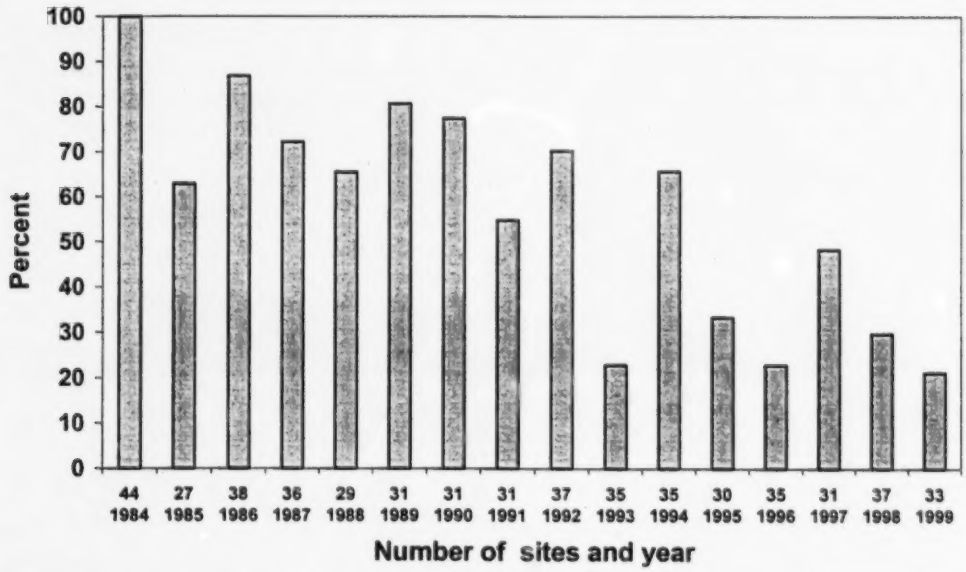

Figure 12. Percent of 27 to 44 sites containing Atlantic salmon fry (age-0$^+$) as determined by electrofishing in the Stewiacke River 1984 to 1999.

Average total parr density at 37 sites in the Stewiacke River in 1999 was 1.38 parr per 100 m^2. Total parr densities as high as 14 parr per 100 m^2 associated with the previous low abundance have not been observed since 1993.

Big Salmon River

The decline of the Atlantic salmon population in the Big Salmon River was lessened by the release of cage-reared Big Salmon River adult salmon in 1994 and 1995. The effect of these releases, verified through observations of survival through to parr for adults placed above barriers, can be seen in the prolonged higher average parr densities of 1996 to 1998 compared to the Stewiacke River densities.

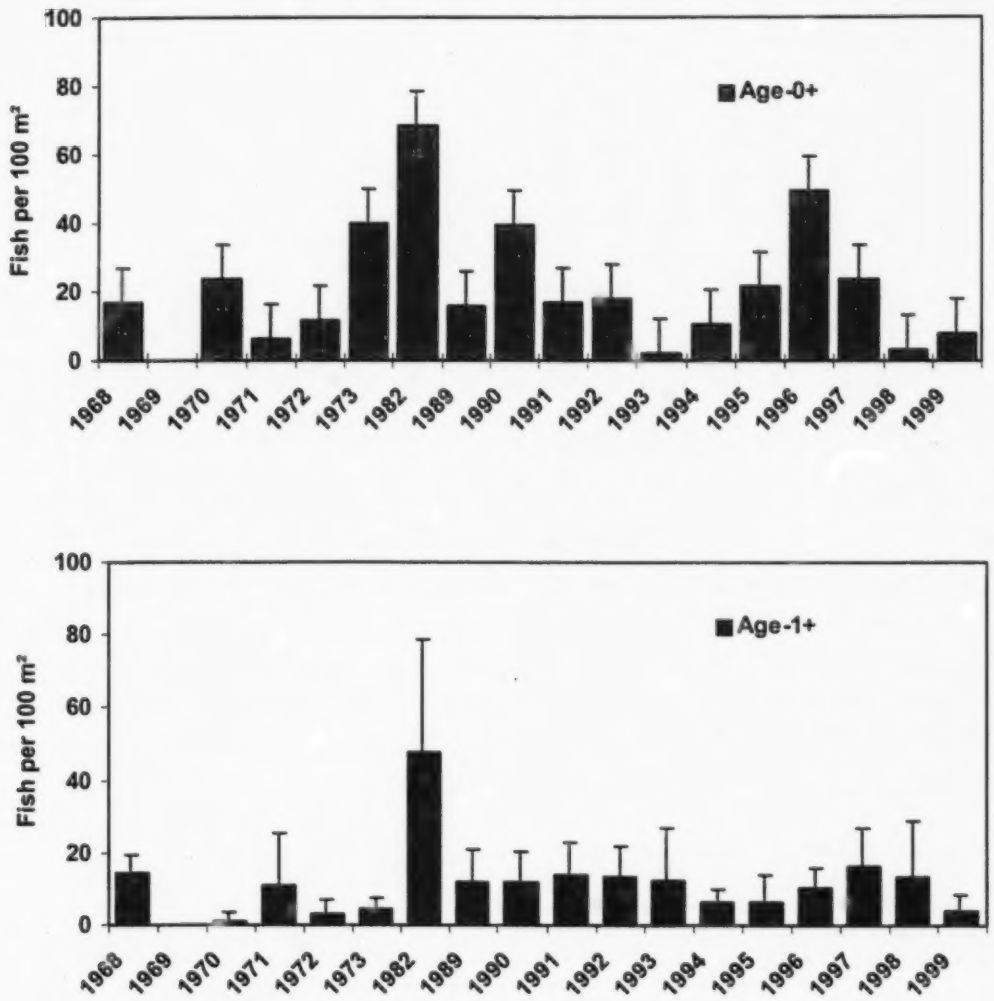

Figure 13. Mean densities per 100 m^2 of age-0^+, age-1^+ Atlantic salmon parr at three to five index electrofishing sites in the Big Salmon River, New Brunswick, 1968, 1970 to 1973, 1982, and 1989 to 1999.

Other iBoF rivers

Parr densities were also low in seven other rivers of the inner Bay of Fundy in 1999 (Figure 14). These locations historically had high salmon densities similar to the monitored rivers of iBoF (Amiro and Jefferson 1997).

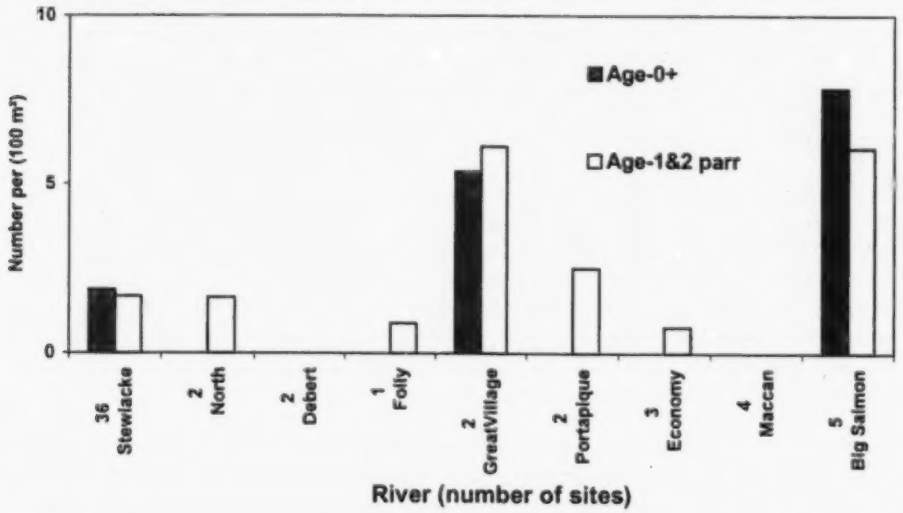

Figure 14. Number of sampling sites and mean densities of age-0$^+$, and total age-1$^+$ and 2$^+$ Atlantic salmon parr from nine rivers of the inner Bay of Fundy, 1999.

Compared to Elson's "normal indices of abundance" of 29 fry and 38 older parr per 100 m^2 (Elson 1967) and compared to historic parr densities from the Stewiacke River, the Big Salmon River and other historic iBoF parr densities (Appendix 3), the 1999 densities are low. These data together with the adult salmon survey data indicate that there are few Atlantic salmon, of any age, left in any inner Bay of Fundy river.

Habitat

Freshwater

Atlantic salmon require clean, cool, flowing water free from chemical or organic pollution.

In the opinion of Elson (1975),

> "The good salmon stream is characterized by moderately low (10 ft/mile = 2m/km) to moderately steep (60 ft/mile = 11.5 m/km) gradient. The bottom or substrate is composed of assorted gravel, cobble and boulder."

Salmon prefer natural stream channels that are stable in the dynamic sense. The hydraulics of stable natural streams is well described in the literature (Leliavsky 1955, Morisawa 1968). These streams develop natural riffle, rapids, pools and flats that Atlantic salmon utilize at one or more of their life stages.

In addition to these hydraulic characteristics are temperature preferences. Parr growth occurs at temperatures above 7° C (Allen 1941). Good salmon streams have summer temperatures

between 15°C and 25°C (Elson 1975). Microhabitat attributes of juvenile salmon habitat have been measured and summarized into stream habitat suitability indices for juvenile Atlantic salmon in both summer (Morantz *et al.* 1987) and in winter (Cunjak 1988). Habitat suitability indices have also been developed for juvenile landlocked salmon (Stanley and Trial 1995).

All iBoF rivers with historic reported salmon catches except the Petitcodiac River and the Avon River (both affected by tidal causeways) were surveyed for Atlantic salmon habitat by a standard aerial ortho-photographic method. All accessible area of freshwater stream habitat with an ortho-photo stream gradient greater than 0.012% is included as salmon habitat. By this method there are about $125{,}475 \times 10^2$ m^2 of salmon production habitat in iBoF rivers, exclusive of the Avon River above the causeway at Windsor, Nova Scotia, the Upper Salmon or Alma River and the Point Wolfe River (O'Connell *et al.* MS 1997 and Amiro unpublished data) (Appendix 1).

Inner Bay of Fundy rivers drain geological areas rich in carboniferous sediments and therefore water quality is good to excellent for rearing of Atlantic salmon. Water quality surveys (Ashfield *et al.* 1993, Lacroix 1994) indicate that pH, a measure of the acidity of the water, is generally over pH 6.0 in these rivers and is not toxic for Atlantic salmon. Alkalinity, a measure of the buffering capacity of the water, is variable but generally sufficient to neutralize acidic precipitation experienced throughout the area. Water hardness, a measure of the available calcium and magnesium necessary for growth, is variable with few high values and consequently specific conductance is variable by tributary.

Forestry and related activities have impacted the upper reaches of many iBoF rivers. However, there is neither legal evidence (records of prosecutions under the Fisheries Act) nor extensive scientific evidence (habitat surveying and losses in juvenile production) to conclude that acute loss of productive capacity for Atlantic salmon could account for the decline in recruitment for the total stock of salmon since 1989.

The presence and increasing frequency and density of brown trout (*Salmo trutta*), a species with habitat requirements similar to Atlantic salmon, has increased since 1989 (Figure 15). There is no evidence of negative interaction between the species in Newfoundland (Gibson and Cunjak 1986). The presence of juvenile brown trout at many electrofishing sampling locations is evidence of the continuing suitability of the habitat to support salmon.

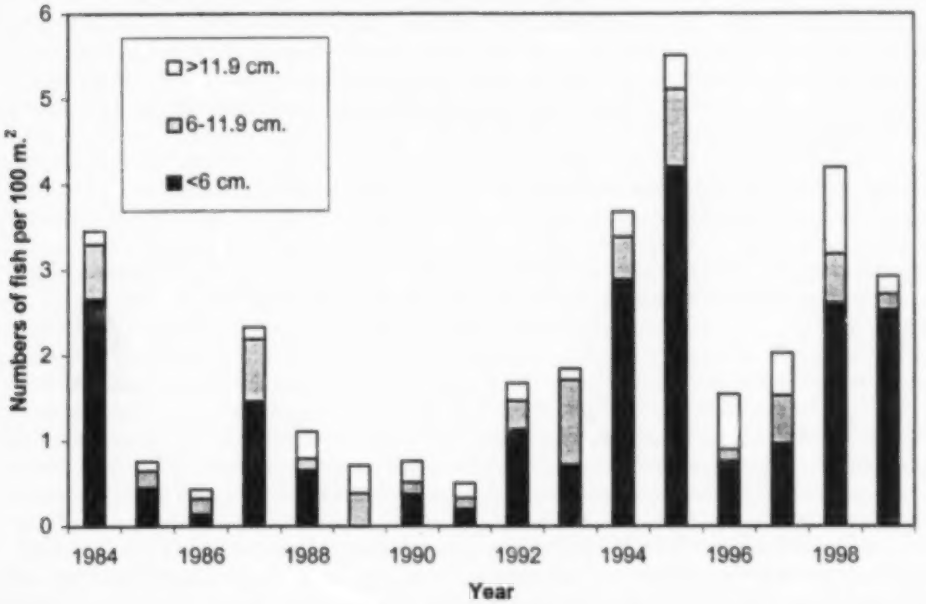

Figure 15. Mean density (per 100 m^2) of three size classes of brown trout (*Salmo trutta*) at 27 to 44 electrofishing locations in the Stewiacke River 1984 to 1999.

The presence of juvenile brown trout in the Stewiacke increased as the density of juvenile Atlantic salmon declined. This inverse relationship should not be interpreted as the cause for the decline of Atlantic salmon in iBoF rivers. This is because: 1) stable sympatric populations of Atlantic salmon and brown trout occur widely and have occurred for many years in the iBoF rivers; 2) the densities of brown trout are low relative to the historic high densities of salmon; and 3) the decline occurred throughout the iBoF and because 4) brown trout do not occur uniformly in rivers throughout the iBoF. These data may be interpreted as an indication that the habitat in at least the Stewiacke River remains suitable for the production of juvenile salmon.

Marine

The infusion of cold oceanic water into the Bay of Fundy and Gulf of Maine provides temperature (Petrie *et al.* 1996, Drinkwater *et al.* 1997) and biotic conditions necessary to support Atlantic salmon on a year-round basis. The temperature preference for Atlantic salmon ranges from 1 to 13°C and peaks at about 7 to 8.5°C with the 80% range being 4 to 10°C (Reddin and Friedland 1993). Temperatures in these ranges are available in the Bay of Fundy during every month of the year. The presence in the Bay of Fundy and Gulf of Maine of sand lance (*Ammodytes* sp.) and euphausids (e.g. *Meanyctiphanes norvegica*) (Gordon and Dadswell 1984), two principal prey species of Atlantic salmon, supports the possibility for local distribution of salmon in the Bay of Fundy. These data, together with the timing and distribution of tag recoveries of iBoF salmon, suggest that some areas of the Bay of Fundy and Gulf of Maine may be essential habitat for inner Bay of Fundy salmon.

Tidal barriers or flow reduction gates have impacted the lower tidal portions of many Inner Bay of Fundy rivers. Barriers exist in at least 25 of 44 major rivers around the Bay of Fundy (Wells 1999). Natural (unobstructed) estuaries of these rivers can be extensive because of the 10m change in elevation of the tides experienced in the iBoF and flow reduction barriers can reduce the productivity and diversity of fish species in the impacted river. However, the main stems of all the remaining salmon producing rivers (those included in the recreational fishery summary), are

unobstructed. Nonetheless, the ecological effect of more than 400 tidal barrages in tributaries to the Bay of Fundy is unknown and is suspected to have resulted in a net loss in productivity. The impact on salmon smolt migration and survival of a loss in productivity in the inter-tidal habitat of the Bay of Fundy is unknown. However, few changes to tidal barrages, new impoundments or reductions to flows have occurred since 1989, one of the last years of moderate recruitment of salmon in the iBoF.

Inner Bay of Fundy salmon post-smolts have been documented to have been recovered throughout the Bay of Fundy at least until September of their smolt year (Amiro 1998b). Recoveries of tagged post-smolts of inner Bay of Fundy river origin were common in the herring weirs set and pursed to catch juvenile herring in the western Bay of Fundy (Fundy Isles area). The occurrence of post-smolt salmon in the Fundy Isles area in the fall of the year is unique to iBoF salmon.

The impact of salmon rearing cages on wild Atlantic salmon utilizing these habitat areas is unknown. A Regional Assessment Process of the Department of Fisheries and Oceans reviewed the possible negative interactions of these facilities on the marine survival of iBoF salmon. The panel consisted of invited experts from many disciplines of fisheries science. While significant negative associations could be seen, no direct evidence for negative interaction was presented. Theoretic negative effects were reviewed and discussed and found to be plausible but unproven. A number of recommendations were brought forward in a Habitat Status Report (Anon. 1999b). These recommendations ranged from risk assessments for new cage rearing sites to improved containment of cultured products, effluents and associated biologics.

Biology

Most iBoF parr smoltify after two years in fresh water. Smolts are similar in size to most seaward migrating salmon (Jessop 1975 and Amiro unpublished data). Seaward migration may begin in the fall of the year but actual movement to salt water usually occurs in late May or June. Inner Bay of Fundy salmon smolts continue to migrate later than most other Atlantic coast salmon stocks and have been observed migrating in July from the Little River, tributary to the Stewiacke River.

Almost all iBoF salmon mature after one winter at sea (Amiro and McNeill 1986, Amiro 1990d). Incidences of salmon maturing after two winters at sea are found in some rivers that were recipient of transferred stocks e.g. Big Salmon River (Jessop 1986). Most repeat salmon spawn in consecutive years and the majority of returns are female (50% to 100% depending on sea age (Ibid.). A high proportion of male parr mature in fresh water and high survival of precocious parr has been observed in one tributary of Stewiacke River. Re-conditioned precocious parr (male smolts that have regained body weight and condition after maturing as parr) migrating as smolts, were as high in condition (lipid composition) as female smolts of the same age (Amiro unpublished data). A scarcity of males capable of fertilizing eggs is unlikely in this population.

In the Big Salmon River, 1965 to 1973, the average age to smolt migration was 2.58 years and the average age to first maturity was 1.07 years (Jessop 1975, 1986). The average generation time was therefore 3.65 years.

Using data collected from the Big Salmon River, 1965 to 1973, the average length of a female iBoF salmon was 61.5 cm and the average egg production was 4,060 eggs. Based on the average gender proportions, iBoF salmon contribute about 3,180 eggs per fish (Amiro and McNeill 1986). These values may be biased high because of the effect of introduced stock during the years the data were collected. However, there was no significant ($p=<0.001$) difference in the slope of length-fecundity of inner Bay of Fundy salmon and salmon from Saint John River, Stewiacke River, Medway River, LaHave River, St. Mary's River and Grand River (Richmond Co. N.S.) (Amiro unpublished analysis). Of the seven length-fecundity relationships examined (Saint

John River, Big Salmon River, Stewiacke, Medway, LaHave, St. Mary's and Grand rivers) the standard error was highest for the Big Salmon River.

Although iBoF Atlantic salmon follow an anadromous life, they have rarely been observed to migrate to the North Atlantic. The population abundance of iBoF salmon is highly variable and has undergone infrequent episodes of low abundance. Low abundance episodes are irregular and not correlated with Atlantic coast stocks (Amiro 1998b). Marine survival is highly variable (Jessop 1986, Ritter 1989). Survival of wild Big Salmon River smolts, 1966 to 1971, ranged from 1.0% to 9.7% and averaged 6.0% (Ritter 1989).

In the presence of highly variable marine survival, population stability is increased through higher annual survival between spawning. High post-spawner survival results in the potential for a high proportion of eggs contributed by repeat-spawning salmon. Counts, aging and analysis of the biological information of the complete sample of 3,334 adult returns to the Big Salmon River, 1965 to 1973, indicated that repeat-spawning salmon contributed 68% of the potential egg deposition. Combined samples from the Stewiacke River commercial and recreational fisheries in 1983 indicated a similar contribution. Using these data as a population model for iBoF salmon, one-sea-winter recruits comprise about 50% of the population but contribute only 25% of the egg deposition. Based on an index of stock and recruitment developed from recreational and commercial catches in the Stewiacke River, eggs from recruits equaled or exceeded that deposited by the parental eggs only once in the years 1975 to 1987 (Amiro 1987). Therefore, over the range of marine survivals observed, recruits did not provide sufficient eggs to replace the parental population. A similar recruitment insufficiency can also be derived from data obtained at the Big Salmon River fence (Amiro unpublished analysis).

Population stability dependent on repeat spawners may also be indicative of a population that can experience periodic genetic bottlenecks when recruitment fails. Such a population potentially undergoes inbreeding depression that can reduce genetic variability. The effect of inbreeding depression on population persistence (i.e. probability of extinction) for small populations of salmon is unresolved. It may be unimportant that small populations undergo extinction from demographic effects, environmental change or catastrophe because of low population while undergoing reduced genetic variability. However, it is unresolved but possible, that genetically diverse small populations are more resistant to extinction than small populations that have lost considerable diversity.

The intrinsic rate of population growth "r" has not been derived from empiric data for iBoF salmon. Population simulations of an iBoF stock suggest a rate similar to other salmon stocks. Rates of r = 0.6 to 1.6 are possible. Further examination and review of the data is required before any specific r value for iBoF salmon can be supported.

Little is known about the feeding behavior of iBoF post-smolts or maturing salmon. Post-smolts were known to frequent areas rich in amphipods and juvenile herring (*Clupea harengus*) in the western Bay of Fundy (Amiro and Jefferson 1996, Amiro 1998b). However, there are no published or archival data on the diet or foraging behavior of inner Bay of Fundy salmon.

Limiting Factors

Population growth of inner Bay of Fundy Atlantic salmon is thought to have been more often limited by marine survival than freshwater productive capacity. For example, in years when marine survival for Big Salmon River was 7.7% to 9.7% (Jessop 1986, Ritter 1989), the population in the Big Salmon River increased from 1,900 to 4,700 adult salmon.

Annual smolt migration from Big Salmon River, 1966 to 1972, reached a peak of 27,259 smolts in 1970 (Jessop 1975). A maximum of 25,658 smolts were produced from an egg deposition of 9.3 eggs per m^2 or 2,970 salmon i.e. 8.6 smolts per spawning salmon. However, there was little

difference in the number of smolts produced at egg deposition rates of 7.5 or 9.3 eggs per m^2. In terms of efficiency, a maximum of 10 smolts per spawner, or 19,462 smolts, was observed from the 1964 escapement of 1,900 salmon, equivalent to an egg deposition rate of 4.2 eggs per m^2. These data indicate that the top of the production curve between eggs and smolts is long and relatively flat and that the numbers of smolts produced was habitat limited above 4.2 eggs per m^2 in the Big Salmon River.

The data from the Big Salmon River are insufficient to establish the relationship between stock and recruitment of adult salmon. The validity of the counts was established at a time when escapements were already high and not when escapements were increasing. The study ended before recruits from low escapements had returned. Therefore, there is not a suitable range of values to define a stock and recruitment relationship between adult stages of Big Salmon River salmon.

The operational conservation requirement for Big Salmon River is 700 salmon. This requirement was derived from an egg deposition rate of 2.4 eggs per m^2 and average biological characteristics. This number of spawners is expected to produce about 20,000 smolts or about 2.2 smolts per 100 m^2. The resulting production rate of 28 smolts per spawning salmon (20,000 smolts from 700 spawners) is intermediate to high among Atlantic salmon rivers and stocks. This rate is justified considering the quality of the Big Salmon River habitat and proximity of the Pollett River, which contributed substantially to the derivation of the 2.4 egg deposition value. The data and analysis indicate that the 700 salmon conservation requirement does not approach the limit to production of smolts in Big Salmon River. While the limiting factors to the production of smolts may be freshwater production area and the numbers of salmon escaping to spawn, escapements since 1991 have been substantially below the conservation requirement, which is well below the freshwater production limit.

Electrofishing densities and smolt monitoring indicate that the reason for low adult salmon returns in the early 1990s was low marine survival, not low number of smolts. The return rate of hatchery smolts to the Stewiacke River is consistent with this conclusion. The last measure of marine survival for an iBoF salmon stock was from native origin, hatchery grown, smolts released into the Stewiacke River. Estimated return rates ranged from 0.0 to 0.42% and were more frequently 0.02%, (Amiro and Jefferson 1996) far below the 6.0% average estimated in 1966 to 1971 (Ritter 1989). In the LaHave River, N.S., a wild smolt was 4.7 times more likely to return than a hatchery smolt (Amiro 1998a). Assuming survival of an iBoF hatchery smolt is one-fourth that of a wild smolt, then marine survival of wild iBoF salmon was 0.08%, which is well below the 3.57% required for replacement of a salmon population producing 28 smolts per spawner.

From these data and analysis, it can be concluded that population growth of iBoF salmon was more often limited by marine survival than by freshwater production capacity and that recent marine survivals have been below that required for replacement of the population. These data point to loss of environmental stability in the marine habitat for iBoF salmon or a catastrophic collapse of the marine habitat and its ability to carry iBoF salmon. There is no evidence for the exact cause for the collapse in marine survival of iBoF salmon in recent years or in previous years.

Circumstantial evidence for the cause of this depression has centered on Bay of Fundy habitat change. Because iBoF salmon have been documented to utilize the marine environment of the Bay of Fundy for their post-smolt migration and growth, the population may be sensitive to ecological change in the Bay of Fundy.

Because some of the marine habitat for iBoF salmon has undergone occupation by commercial fish farming, there is the possibility of a negative interaction between commercial salmon farming and the survival of wild inner Bay of Fundy salmon. The mechanisms for negative interaction have been reviewed and include disease, predator attraction, habitat interference and habitat change or interaction among these effects (Amiro 1998b).

The presence of a non-detected pathogen has not been ruled out but expert opinion suggests that it is unlikely the cause of the decline (Anon 1999b). The presence of fish farming operations and changes in the harvesting regulations of marine mammals has led to an increase in the abundance and types of marine mammals in these areas. Predators of salmon are attracted to salmon in and leaking from salmon farms. There is considerable effort and expense to repel these predators. The possibility also exists that the presence of salmon farms in what may be essential marine habitat for wild iBoF salmon has broken a critical link in the marine migration of iBoF salmon. There is also the possibility that large scale changes in the marine habitat of the Bay of Fundy may have been brought about by many tidal barriers placed at the mouths of many of the smaller and some of the larger rivers.

Special significance of the species

The observed characteristics and population genetics place the inner Bay of Fundy salmon stock as distinct among Atlantic salmon stocks worldwide. The mtDNA analysis by (Verspoor *et al.* 2002, *in preparation at the time of the initial document)* indicates that the iBoF salmon is one of few distinct evolutionary lineages of Atlantic salmon.

The degree of public interest in the plight of inner Bay of Fundy salmon has been reduced by: 1) the historic variability in the stock; 2) the loss of advocates because of the closed commercial and recreational fisheries; and 3) the diversity of environmental concerns within the Bay of Fundy.

Because salmon were considered a commercial fish they were not included as a species of interest to the international Canada - United States, Gulf of Maine Committee, a joint federal, provincial and state committee struck to examine issues of the Bay of Fundy and Gulf of Maine.

Articles published in 1998 by the Atlantic Salmon Federation, an internationally affiliated interest group, brought the plight of iBoF salmon to a wider audience. Publication of the Habitat Status Report on the Interactions of Wild and Farmed Atlantic salmon in the Maritime Provinces (Anon. 1999b), which included the issues concerning the plight of iBoF salmon, further increased interest both in the public and in the fish farming industry. Considerable confusion exists among the general public and others with the separation of inner Bay of Fundy salmon from that of outer Bay of Fundy and Atlantic coast salmon stocks.

The population size of wild Atlantic salmon through the North Atlantic is at an unprecedented low abundance (Anon. 1999a). Because of the low population numbers and uniqueness of the stock, advocates for iBoF salmon persistence have petitioned governments to take immediate action to prevent their extinction and to fund research to document the causes for their decline.

Recommendations

The Science Steering Committee for inner Bay of Fundy salmon (an ad hoc committee of the Salmon Fishing Areas 22 and 23 Zone Management Committee, a client consultation committee) decided in September 1998, on two priority actions:

1) live gene banking of iBoF salmon, and
2) gathering scientific evidence of the migration and location of the loss of inner Bay of Fundy salmon.

After considering the options, the Committee advised collection of parr and rearing to maturity of two iBoF salmon river stocks. The intention of the project was to maintain the population while maximizing genetic diversity until a permanent solution can be found. In October of 1998 the first parr were collected from Big Salmon River and from Stewiacke River (Amiro 1999). These rivers

were selected because they are the two largest rivers containing iBoF salmon. Parr were certified disease free and cultured at two sites, Mactaquac Fish Culture Station and the Cobequid Fish Culture Center. Indications from juvenile monitoring programs in rivers of the iBoF in 1999 were that this was the last opportunity to collect a representative genetic sample of the population. Because the pedigree portion of the program was unfunded and has not yet taken place, it was unknown at the time if the live gene banking effort had the potential to maintain sufficient genetic diversity in the stock. It was recommended that the program be continued and all objectives of the program carried out. Supportive rearing and perhaps supportive breeding may be essential to the preservation of the inner Bay of Fundy salmon.

Evaluation

The Inner Bay of Fundy Atlantic salmon populations have declined because of the recent acute depression in marine survival. In comparison to the last reduction, 1958 to 1965 in salmon recruitment to inner Bay of Fundy rivers as indicated by recreational catches and commercial catch, (Swetnam and O'Neil 1985; O'Neil and Swetnam 1991), the current decline is more severe. The severity of the recent decline may be interpreted from angling and juvenile salmon densities collected after the 1960's decline compared to data available for the 1990's.

Recovery of iBoF salmon first involves determination of the cause(s) and then initiating appropriate corrective actions. The iBoF salmon populations do not appear large enough to withstand the time required to collect the information necessary to resolve the collapse of the stocks. In fact, without supportive rearing or breeding there would not be enough iBoF salmon remaining to provide the animals necessary to research the problem.

Although historically these populations have undergone periods of low marine survival, population levels are much lower today than previously observed. There appears to be few population refuges from which the stock could rebuild. Without immediate supportive rearing and perhaps breeding, these stocks are likely to become extinct. This conclusion is based on the low population size, under-distribution, reduced longevity caused by lower survival to repeat spawning and reduced potential population growth rate caused by reduced marine survival. Because the populations are severely under-distributed and at low abundance, the threat to persistence posed by random demographic variations (e.g. fecundity, gender proportions and age composition) are heightened. In addition to the usual demographic vagaries are threats posed by normal environmental variation, e.g. temperatures, flows and forage, and debilitating environmental trends, e.g. prolonged droughts, temperature extremes and high predator abundance.

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Appendices

Appendix 1. List of rivers of the inner Bay of Fundy where Atlantic salmon (*Salmo salar*) were historically reported, accessible rearing area, mean and standard deviation of the reported recreational catch and effort, 1985 to 1989, years of reported electrofishing, knowledge of the presence of salmon, years of nuclear DNA analysis and mitochondria DNA analysis.

		Accessible[1]	Recreational catch 1985 - 1989							Presence of	Years of genetic analysis	
		rearing area	small (<63.0 cm)		large (>= 63.0 cm)		effort (rod days)		Years of electrofishing	A. salmon	nuclear	mitochondrial
Number	River	(m^2 /100)	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	reported to or by DFO	in 1999	DNA	DNA
1	Cornwallis	1,706	5	8	4	6	86	56	1979, 1982	Unknown		
2	Gaspereau	3,856	35	17	29	12	482	77	1995	Present	1997, 2000	2000
3	St. Croix, Hants	4,283	24	32	2	4	170	157		Unknown		
4	Kennetcook	3,976	2	3	0	1	18	11	1978b.	Unknown		
5	Shubenacadie	10,340	92	66	37	26	870	415	1968, 1969a., 1977a.	Unknown		
6	Stewiacke	13,086	649	513	291	189	4955	1496	1968-69, 1976-77, 1980-81, 1983-99	Present	1995, 1996, 1999, 2000	2000
7	Salmon, Colchester	13,468	86	66	24	10	418	188	1972-73a., 1976, 1990, 1998-99	Unknown		
8	North, Colchester	4,485	79	46	11	9	364	124	1972-73a., 1976, 1990, 1996-99	Present		
9	Chiganois	3,369	0	0	0	0	21	12	1972-73a.	Unknown		
10	Debert	3,499	28	25	12	11	252	125	1980, 1998	Absent		
11	Folly	2,896	35	27	9	12	215	96	1996, 1997,1999	Present	2000	2000
12	Great Village	2,587	7	12	1	1	19	17	1972, 1980, 1997-98,1999	Present	2000	2000
13	Portapique	3,309	11	8	1	1	44	15	1978b., 1996-99	Present	2000	2000
14	Bass, Colchester	696	0	0	0	0	0	0		Unknown		
15	Economy	2,386	14	16	5	6	161	67	1977a., 1996-99	Present	2000	2000
16	Harrington	629	0	0	0	0	0	0		Unknown		
17	Parrsboro	705							1999	Present		
18	Diligent	335	0	0	0	0	0	0		Unknown		
19	Apple	2,111	5	5	4	6	60	36	1981	Unknown		
20	River Hebert	2,282	42	40	7	7	397	216	1981	Unknown		
21	Maccan	8,228	80	53	14	13	766	293	1966a., 1977a., 1996-99	Absent		
22	Tantramar									Unknown		
23	Petitcodiac	28,150							1997-99	Present		
24	Demoiselle									Unknown		
25	Crooked									Unknown		
26	Shepody								1983	Unknown		
27	Upper Salmon		15	18	N/A	N/A	128	133	1984-85, 1987, 1993-95	Unknown		
28	Point Wolfe								1983-85, 1987-1995	Unknown		
29	Big Salmon	9,093	131	118	N/A	N/A	1280	1172	1968, 1970-73, 1982, 1989-99	Present	2000	2000
30	Irish									Present	2000	2000
31	Mosher									Present		
32	Black									Present	2000	2000

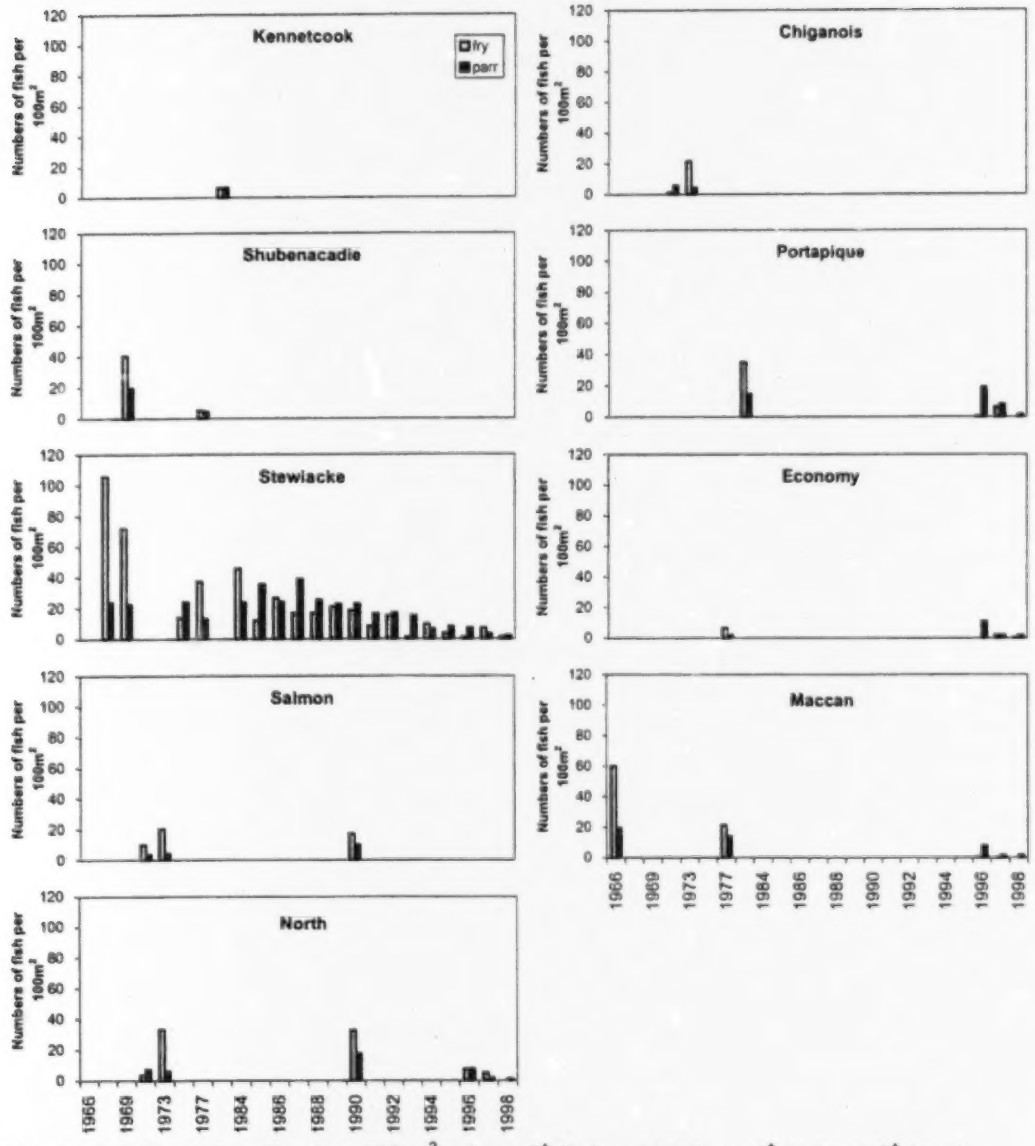
[1] Rearing area based on stream gradient >0.12% and <25%.

a. Gray *et al.* (1978)

b. Cameron and Gray (1979)

Appendix 2. History of enhancement activities in rivers of the inner Bay of Fundy with respect to origin of stock used 1976 to 1999.

Rivers	Enhanced		
	native	locally	distant
Cornwallis	X	X	X
Gaspereau	X		X
St. Croix, Hants Co.			
Kennetcook		X	
Shubenacadie			X
Stewiacke	X		
Salmon, Colchester Co.			
North, Colchester Co.			
Chiganois			
Debert	X		
Folly			
Great Village			
Portapique			
Bass, Colchester Co.			
Economy			
Harrington			
Parrsboro		X	
Diligent			
Apple			
River Hebert			
Maccan			
Tantramar		X	
Petitcodiac	X	X	X
Demoiselle			
Crooked		X	X
Shepody			X
Upper Salmon			
Point Wolfe		X	X
Big Salmon	X		
Irish			
Mosher			
Black			



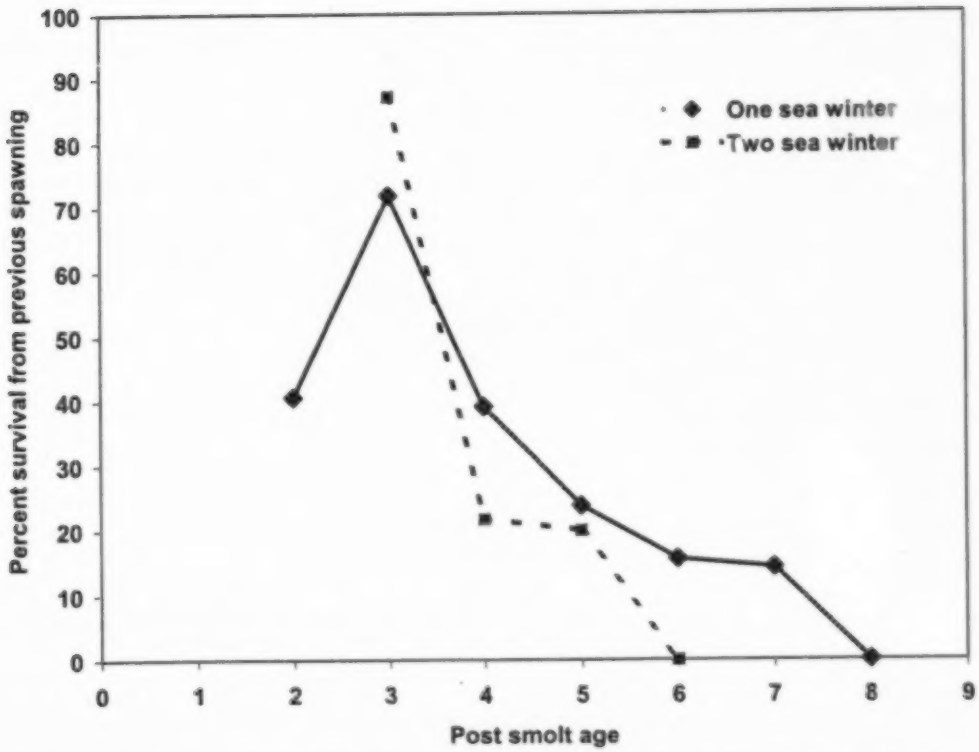
Appendix 3. Mean densities (per 100 m^2) of age-0^+ (fry) and total age-1^+ and age-2^+ (parr) Atlantic salmon determined by electrofishing in eight rivers of the inner Bay of Fundy, 1966 to 1998, with densities determined an index river, Stewiacke River, for comparison. All zero values are the result of no electrofishing data being gathered for a river in that year.

Appendix 4. Distribution by age-at-first maturity, one sea winter (1SW) and two sea winter (2SW), post-smolt age, spawning history mean length, fecundity, percent female, and percent-at-age of Atlantic salmon of the Stewiacke River determined from 298 aged scale samples collected from the commercial and the angling fisheries, 1983.

Post smolt age	Spawing history 1st	2nd	3rd	4th	Fresh water age	Number	Mean length (cm)	Mean fecundity (eggs)	Percent female	Percent of sample
1SW										
1	0				2	204	52.7	2,999	73	68.5
1	0				3	12	54.9	3,252	50	4.0
2	1				2	38	64.4	4,613	66	12.8
2	1				3	8	61.8	4,192	62	2.7
3	1	2			2	9	73.0	6,331	89	3.0
3	1	2			3	2	71.6	6,013	100	0.7
3	1				2	7	78.0	7,610	100	2.3
5	1	2	3	4	2	1	96.3	14,923	100	0.3
2SW										
2	0				2	7	72.1	6,125	100	2.3
2	0				3	2	75.0	6,814	100	0.7
3	2				2	3	79.4	8,012	66	1.0
3	2				3	1	–	–	–	0.3
4	2	3			2	4	80.8	8,436	100	1.3

Appendix 5. Distribution by age-at-first maturity, one sea winter (1SW) and two sea winter (2SW), post-smolt age, spawning history mean length, fecundity, percent female, and percent-at-age of Atlantic salmon of the Big Salmon River determined from aged scale samples collected from 3,334 samples collected from a counting fence operated 1965-1973.

Post smolt age	Spawing history 1st	2nd	3rd	4th	5th	6th	Number	Mean length females (cm)	Mean fecundity (eggs)	Percent female	Percent of sample
1SW											
1	0						1,659	52.9	3,142	66	49.8
2	1						673	63.1	4,263	67	20.2
3	1	2					483	71.9	5,546	81	14.5
4	1	2	3				189	78.1	6,676	92	5.7
5	1	2	3	4			45	83.1	7,752	100	1.3
6	1	2	3	4	5		7	83.5	7,846	100	0.2
7	1	2	3	4	5	6	1	88.0	8,975	100	0.0
2SW											
2	0						132	71.6	5,497	89	4.0
3	2						115	77.5	6,557	86	3.4
4	2	3					25	81.6	7,412	92	0.7
5	2	3	4				5	81.6	7,412	80	0.1



Appendix 6. Percent survival from previous spawning by age at first return (one-sea-winter 1SW, and two-sea-winter 2SW) as indicated from ages determined from scale samples collected at the Big Salmon River counting fence, 1965-1973.